IODINATION OF PUBLIC WATER SUPPLIES

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

June, 1967

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to Dr. A. P. Black, my committee chairman, who provided the guidance, assistance and inspiration which were required to complete this dissertation. His competent teaching and advice have been most valuable in training me for my profession; likewise, his expression of enthusiasm toward life and work has provided an excellent example which I shall try to follow. The contributions made by others who served on my committe, namely, Dr. H. A. Bevis, co-chairman, Professor J. E. Kiker, Jr., and Dr. B. G. Dunavant are also gratefully acknowledged.

I am indebted to R. P. Vogh, J. B. Warrington, J. J. Smith, Jr., Margaret Whittle, G. P. Whittle, Michael Keirn, Patricia Green and others for rendering valuable assistance in carrying out this work. My thanks to Mrs. Janice Larson for her fine help during the performance of this work and for typing the final manuscript.

Appreciation is extended to my wife, Marjorie, who, as she always has in our life, helped and encouraged me in this work. Her patience and understanding while providing a home in the absence of a husband and the inspiration of my two sons through cheerful greetings and wanting a father at home are also greatly appreciated.

To Union Carbide Corporation, Nuclear Division, for making this study possible by granting me a leave of absence, and to Mr. E. G. Struxness, Drs. T. Tamura and F. L. Parker of Oak Ridge National

Laboratory, for their guidance and encouragement, sincere appreciation is extended.

Many thanks go to my parents and relatives who have helped in every way possible to provide the opportunity of attending college and easing the financial strain. Financial support is also acknowledged through a traineeship from the United States Public Health Service under Training Grant No. 2T1RH3-06(66), and support of the project through Demonstration Grant WPD-19-04-66 awarded by the Federal Water Pollution Control Administration of the Department of the Interior.

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June, 1967

Chairman: Dr. A. P. Black
Major Department: Bioenvironmental Engineering

A comprehensive sampling program which included both surface and ground water was conducted to show the extent to which the Floridan Aquifer is receiving pollutants from surface sources on the periphery of the City of Gainesville. The primary routes by which pollutants enter the ground near the city are Alachua Sink and two drainage wells near the west end of Lake Alice. Each is located about three miles from the city's well field, Alachua Sink to the south and Lake Alice to the west.

Both chemical and bacteriological determinations show that pollutants of sewage origin are present in wells comprising the city's well field. The presence of iodides in water from Lake Alice provided a unique tracer to show that water entering the ground through the two shallow drainage wells travels east past wells owned by the University of Florida and into the city's well field. The highly colored water which is entering the ground through Alachua Sink is believed to be traveling northward in the upper stratum of the aquifer into the shallower wells in the city's well field.

After successful studies at three state correctional institutions at Lowell, Florida, had shown iodine to be an effective and desirable disinfectant for water, its use in other systems was investigated. The iodination of a private water supply at Marietta, Ohio, provided valuable background data by showing that a low HIO residual could be maintained in the presence of high concentrations of ammonia and other industrial pollutants.

The size of the Gainesville water system as well as the polluted water which serves as its source of supply made the Gainesville system a desirable one on which to conduct further studies. Laboratory studies using pipe which were removed from the distribution system showed that a low HIO residual could be maintained in the presence of chloramine, tubercules, scale and organic matter. Both taste and odor slowly developed, with at least 48 hours required before either became objectionable.

The detention time of water within the distribution system was determined to be less than 48 hours except for a few areas served by dead-end mains.

Iodination of the supply for a brief period was accomplished by adding iodine as the iodide ion to the chloramine residual leaving the treatment plant. Maximum use of the iodine was obtained through reoxidation of the iodide ion by chloramines as the water passed through the distribution system.

Iodination of the supply was terminated 12 hours later due to the presence of an objectionable taste and odor in the water which had

not been predicted by laboratory studies.

Present laboratory studies are centered around elucidating the agent or agents responsible for the taste and odor.

I. INTRODUCTION

Water, our most indispensable natural resource, has long been looked upon as a symbol of purity and health. However, the installation of the first municipal water supply system in the mid-1800's witnessed an increase in the incidence of gastrointestinal diseases, and typhoid fever took its share of victims. The use of polluted water sources for such systems accelerated the cycle of enteric pathogens from man to water to man.[1] This paradoxical situation, however, served to call attention to the part played by public water supply systems in either disseminating or protecting against water-borne diseases.

Since the late 1800's, much progress has been made in water treatment in America. America's first municipal filtration plant was built in 1872. The turn of the century witnessed the development of the American rapid sand filter as a substitute for the older English slow sand filter. Lime-soda softening was first used in 1908. In the same year bleaching powder was first used in this country for continuous chlorination, and in 1910 liquid chlorine was introduced as a disinfectant for water.

A combination of these events and an understanding of the mode of infection has reduced the death rate due to typhoid fever from 59 per 100,000 in 1881-1885 to less than 0.1 per 100,000 today. Outbreaks of other gastrointestinal diseases caused by enteric pathogenic bacteria have decreased. Of all of these factors, however, continuous

chlorination has probably been the most important single factor in dramatically reducing the incidence of water-borne diseases. Its use for water disinfection is without question one of man's greatest advances in the field of preventive public health.[1,2]

In addition to numerous strains of bacteria, over 100 different viruses are known to be excreted with feces by man.[2,3,4,5] Since viruses are found in human waste, they, like bacteria become water-borne, spread through water systems and have been known to cause disease.[6] Berg[7] recently reported that at least six viruses have been isolated from four different areas of the water distribution system of Paris, France. The outbreak of infectious hepatitis in New Delhi, India, in 1955 is a classic example of a water-borne enteric virus outbreak occurring when the treated water met accepted standards of bacterial quality.[8]

Recently, evidence has accumulated to indicate that chlorine is not the ideal disinfectant for water.[9] As pointed out in the Gross Report[9] to the Surgeon General, chlorine is ineffective against certain microorganisms in the concentrations normally used for the disinfection of public water supplies. Nematodes, slime bacteria, certain viruses and cysts of *Entamoeba histolytica*, some of which are pathogenic, are known to be somewhat resistant to chlorine in low concentrations. Further drawbacks to the use of chlorine include its decreasing bactericidal effectiveness with increasing pH values, its reactions with ammonia and its high chemical reactivity, which makes it difficult to maintain stable residuals and frequently results in the formation of tastes and odors when certain impurities are present.

Some authors[9,10,11] have suggested that a reassessment of the sense of security concerning accepted water treatment practices is needed. Specifically, the present methods of disinfection warrant research effort. At the present time, the best defense against an outbreak of water-borne disease is the presence of sufficient effective disinfectant in the water to insure that it is safe to drink.[12]

Since 1953, iodine has been recognized as a potential disinfectant for water.[13] Iodine may be the preferred disinfectant in situations where chlorine is relatively less effective, namely, for waters whose pH is above pH 8.0 and for waters containing high concentrations of organic material and/or ammonium compounds. By virtue of the fact that iodine is a fast-acting viricide and has advantages in areas where chlorine has disadvantages, it has been suggested that under field conditions iodine may be the better disinfectant.[11]

Iodine has been shown to be effective as a disinfectant for swimming pool water, for emergency water supplies, and for public water supplies.[13,14,15] Studies carried out in conjunction with the iodination of the water supply at three state institutions at Lowell, Florida, have shown no adverse physiological effects on a human population as a result of drinking iodinated water.

The next logical step in the development of iodine for use in public water supplies is to demonstrate that iodine can be used in a large and more highly polluted water supply. The water supply for the city of Gainesville, Florida, meets these requirements and has been selected for the present study. This study was designed and initiated

to accomplish the following objectives:

1. Determine the extent and magnitude of organic pollution in the Gainesville area by evaluating:
   (a) The bacteriological quality of local surface and ground waters.
   (b) The presence and amount of organic pollutants in area well water.
   (c) The recycle of iodide from the distribution system back into area wells by observing the change in base-line iodide levels resulting from the use of iodine for disinfecting the water of the University of Florida swimming pool for the past three years.
2. The addition of iodine to the treated water of the City of Gainesville in order to determine:
   (a) The persistence of I_2 or HIO residuals throughout the system.
   (b) The rate of buildup, if any, of iodates in the distribution system.
   (c) Any change in bacteriological quality of water in the distribution system.

While stable iodine was used in this study, it should be remembered that radioactive iodine would be expected to take the same route should it enter the cycle of water from any source.

The data and conclusions derived from both the applied and laboratory studies are presented and described in the following pages.

II. LITERATURE REVIEW

Iodine

Historical

A brief look at a time table of events quickly reveals the extent to which the importance of iodine has been recognized. For example:

1811 - Discovered by Bernard Courtoit.[16]

1816 - First used in the treatment of goiter by Proust.[17]

1833 - Iodized salt recommended by Baussengault for goiter prevention.[17]

1839 - Tincture of iodine used for the treatment of wounds by Davies.[18]

1867 - Used for treatment of gonorrhea by Watson.[19]

1873 - Davaine demonstrated the sporicidal activity of iodine.[20]

1915 - Used for the disinfection of drinking water.[21]

1922 - 1967 - During this period more than 30 technical papers were published on the use of iodine for water disinfection. A few of the more important papers are briefly summarized.

Iodine as a disinfectant for drinking water. - Chang and Morris,[13] in 1953, reported that elemental iodine is a suitable agent for the emergency disinfection of water supplies. Their work showed iodine to be effective against most types of pathogenic organisms within a reasonable time at a concentration of a few parts per million.

In the same year, Morris, Chang, Fair, and Conant[22] reported that several iodine-releasing compounds were suitable for field use in disinfecting water with iodine. Their studies were primarily responsible for its adoption by the military for the disinfection of canteen water in the field.[22]

Later, studies conducted at Lowell, Florida, contributed much to the present knowledge of iodine as a disinfectant for water supplies.[14] The studies have demonstrated that the consumption of iodinated water by the inmates of three state institutions over a period of more than three years has had no detrimental effect on general health or thyroid function.[14,23] Iodine was also shown to be as effective as chlorine as a bactericide.

In a very recent publication, Berg[11] shows that iodine is an effective viricide and suggests that under field conditions it could be a better disinfectant than chlorine.

Iodine as a disinfectant for swimming pool water. - Swimming pool studies likewise have shown iodine to be an effective disinfectant with few disadvantages and many desirable qualities which chlorine does not possess.[15,24,25,26]

Formation of Iodates

Wyss and Strandskov[27] found that in buffered solutions and at relatively high pH values HIO is rapidly converted to iodate. Chang[28] showed that the iodate ion had no disinfecting ability. These findings raised serious questions concerning the possibility of maintaining stable residuals throughout distribution systems carrying water of high pH values.

However, the high concentrations of iodine used in the iodate studies cast some doubt on the results which might be obtained if lower concentrations were used.

Subsequent laboratory studies conducted by Black, Kinman, Thomas, Freund, and Bird[14] showed that in a potable water environment iodate formation at pH values as high as pH 9.0 is not significant. When 1.0 ppm iodine was used the maximum concentration of iodate ion found over periods of from 4 to 17 days was 0.05 ppm.

Jabero[29] showed that iodate formation was not significant at pH 9.0 in a small distribution system.

Chemistry of Iodine in Dilute Aqueous Solutions

The chemistry of iodine in dilute aqueous solutions as it applies to a potable water environment has been fully discussed by Chang,[28] who points out that there are important differences between the behavior of chlorine and iodine which would be expected to markedly alter their effectiveness as sanitizing agents.

The Iodide Content of Natural Waters

Available data show that the concentration of iodide in natural waters in the United States varies widely. Tables 1, 2, and 3[30,31] give the concentration of iodine found in the waters of certain lakes, rivers and wells in the United States. These data show that although iodine is widespread in nature, its concentration in most waters is extremely low.

Because of the low concentrations of iodine found in most fresh water sources and the prevalence of endemic goiter, this country witnessed the first trials of the addition of iodine to public water supplies

Table 1

Iodine Content of Water from Four of the Great Lakes[30]

Lake	Iodine (ppb)
Lake Superior at Duluth, Minn.	0.01
Lake Superior at Marquette, Mich.	0.02
Lake Michigan at Milwaukee, Wis.	0.015
Lake Michigan at Winnetka, Ill.	0.10
Lake Michigan at Chicago, Ill.	0.12
Lake Erie at Cleveland, Ohio	0.86
Lake Ontario at Toronto, Canada	1.45
Average	0.37

for the prevention of that disease during the 1920's. Supplies at Rochester, N. Y., Anaconda, Mont., Sault Ste. Marie, Mich., and Virginia, Minn. were iodized by the addition of low concentration of sodium iodide to the water for a short interval of time prior to the general acceptance of iodized salt.[32,33,34]

Iodination of water supplies is not new. Only the form of iodine and the purpose of addition has changed.

Although the concentration of iodide in surface waters and most ground waters is only a few parts per billion, some natural brines contain iodides in concentrations ranging from three to 65 ppm.[35] By

Table 2

Iodine Content of Water from Some United States Rivers[30]

River	Iodine (ppb)
Mississippi River at Minneapolis, Minn.	0.88
Mississippi River at St. Paul, Minn.	0.83
Mississippi River at St. Louis, Mo.	3.52
Mississippi River at New Orleans, La.	7.70
Missouri River at Kansas City, Mo.	1.69
South Platte River at Denver, Colo.	0.77
Scioto River at Columbus, Ohio	0.21
Cumberland River at Nashville, Tenn.	0.22
Susquehanna River at Harrisburg, Pa.	0.23
James River at Richmond, Va.	0.60
Potomac River at Washington, D. C.	0.72
Oconee River at Atlanta, Ga.	3.20
Average	1.71

recovering the iodide these sources could provide an almost inexhaustible supply of iodine should the demand for iodine warrant the exploitation of this vast source.

Table 3

Iodine Content of Water from Some Pennsylvania Wells[31]

City	Iodine (ppb)
Allentown	2.4
Bethlehem	2.5
Warren State Hospital	2.5
McKees Rocks	1.0
Meadville	1.7
Beaver	0.0
Alliquippa	0.3
Average	1.5

Pollution of Ground Water from Surface Sources

While the presence of pollutants in streams may be readily noticeable, pollutants may also exist in ground water and present an equally great hazard to the health of its users. The Broad Street Well in London, 1854, is an historic example of ground water pollution and its role in the spread of disease.[36] An early example of the pollution of well water as evidenced by the presence of detergents occurred in 1958 on Long Island.[37] Many other cases were soon reported.[38,39,40,41,42]

In areas underlain by limestone aquifers short circuiting is frequently encountered through numerous channels, sink holes or even

caverns resulting from the solvent action of surface water containing carbon dioxide on the underlying limestones. This is called "Karst" or solution-type topography. In such areas the physical, chemical, and bacteriological quality of ground water is variable, fluctuating with rainfall and waste disposal practices in the area.[43]

A series of typhoid outbreaks in southeast Minnesota between 1939 and 1943 were shown to be due to pollution entering porous limestone strata from surface sources.[44]

The gastroenteritis epidemic at Riverside, California, in May, 1965, reportedly affected 18,000 out of a population of approximately 130,000. Although a great many questions relative to the epidemic remain unsolved, contaminated water from a well which had been known to show evidence of surface contamination is suspected as being the cause of the outbreak.[45]

In the City of Gainesville, Florida, ground water pollution has become evident. In January, 1964, the presence of detergents in the well water caused foam to build up as high as nine feet over the recarbonation basin as shown in Figure 1.[46] A thorough discussion of the pollution problem which exists in the Gainesville area will be presented later in this work.

Indicators of Pollution

ABS and LAS. - Alkyl benzene sulfonate (ABS), the primary surface active agent used in detergents for many years, is not a substance which naturally occurs in nature. Since it is widely used as a household detergent its presence in water is thus an indication of pollution by

Fig. 1 - FOAMING AT THE WATER TREATMENT PLANT
DUE TO POLLUTION OF CITY WELLS

sewage or other man-made wastes.[41,47]

The replacement of the original branched chain nonbiodegradable detergents (ABS) with the newer straight chain and more biodegradable materials (LAS) has reduced the problem of pollution by detergents to a considerable extent.[48,49] However, along with the elimination of complaints due to the presence of detergents in water has gone a valuable indicator for the presence of sewage pollution.

<u>Phosphates</u>. - Closely associated with the presence of ABS or LAS in domestic wastes is the presence of phosphates. Phosphates are used in detergents as "builders" and are usually added in the form of sodium tripolyphosphate, sodium hexametaphosphate, tribasic sodium phosphate, or tetra sodium pyrophosphate.[42,50] Collectively, these forms of phosphate are called polyphosphates.

Apparently, a combination of biological action and hydrolysis is responsible for the degradation of polyphosphates through sewage treatment. Engelbrecht and Morgan[51] report that 90 percent of the phosphate present in the sewage effluent is already in the orthophosphate form. Polyphosphates are likewise subject to hydrolytic degradation in natural waters, the rate of reversion varying with the different chemical and physical characteristics of the water.[51]

As an indicator, the presence of polyphosphates is associated with fairly recent sewage pollution. Orthophosphates on the other hand may indicate the presence of pollution from either domestic waste or drainage from agricultural land.[51] It is important, therefore, to consider the results of other chemical analyses and a survey of the drainage

area in evaluating the source of phosphates in water.

Carbon-chloroform extract (CCE) and carbon-alcohol extract (CAE).[52] The absorptive power of activated carbon has long been known.[53] Through the years it has found many applications in industry as a deodorizer and decolorizing agent.[54] Its remarkable ability to absorb organics from water is the basis for two determinations known as "carbon-chloroform extract" or CCE and "carbon-alcohol extract" or CAE.

By running several thousand gallons of water through a bed of activated carbon a sufficient quantity of the organic material can be recovered by drying and then extracting first with chloroform and then with ethyl alcohol.[55,56] Its use as a quantitative measure of pollution, however, is unjustified since recoveries from the chloroform extraction are reported to range from only 50 to 90 percent, and ethyl alcohol extraction from 20 to 30 percent.[57,58,59,60]

One of the most significant contributions which CCE and CAE determinations can make as indicators of pollution is their use as a monitor to determine undue stress on a stream from pollutants arising from industrial or domestic sources. By determining both CCE and CAE it is possible to determine the relative quantities of different types of pollutants. Organic pollutants arising from the various chemical manufacturing industries, as well as petroleum-based pollutants, are mainly recovered in the chloroform extract. The alcohol extract contains detergents, as well as materials originating from algal activity, organic matter in soil, decay of vegetation, decomposition of sewage and other natural sources.[52,58,61]

Field studies have shown that where the primary pollutants are

from chemical industries, the CCE exceeds the CAE, and when sewage is the predominant pollutant, the CAE exceeds the CCE by a factor of from four to six.[52,57,58,61]

Together, CCE and CAE values are a valuable index for determining the relative organic content of water and the relative quantities of different types of pollutants. Where concentrations of 200 ppb have been found, the taste and odor of the water are usually poor.[62]

The sampling program of the national water quality network has provided valuable information regarding the quality of finished waters in the United States and Puerto Rico. Much of the earlier data which have been obtained have been recently published by Taylor.[63] Of 172 water supplies checked, only two values for CCE were greater than the 200 ppb limit set by the 1962 <u>Drinking Water Standards</u>.[64] The mean was determined to be 66 ppb with the range extending from 7 to 267 ppb.

<u>Organic color</u>. - Gainesville, Florida, is located within a 300-square-mile area in the southwest section of Alachua County which has no surface outflow.[65] The few small streams in the area terminate in sink holes and most rainfall leaves as underground flow. Most lakes and streams in the area contain waters with high organic color; thus, the presence of high organic color in ground waters indicates the possibility of local surface water pollution.[66]

III. PLAN OF RESEARCH

Preliminary Work at Marietta, Ohio

Description of Problem

In response to a request from the Mine and Metals Division of the Union Carbide Corporation at Marietta, Ohio, an investigation of their plant water supply was made to determine the feasibility of disinfecting it with iodine. The water was believed to contain phenol since chlorination was producing highly objectionable tastes and odors. Since it has been shown that no odor or taste is produced by phenols in the presence of iodine in low concentrations and in view of the highly successful studies at Lowell, Florida, it was felt that iodination of the supply might solve the problem.[67] A request for permission to iodinate the supply was approved by the Ohio Department of Health.

Source of Water

The water supply is derived from four wells penetrating an unconsolidated glacial formation. Recharge of the aquifer is primarily from local rainfall and from the Ohio River which flows from 125 to 600 feet from the four wells. A comparison of the water level in the wells and the observed water level in the Ohio River indicates that the two levels are approximately the same, and from the nature of the formation it is suspected that the ground water level in the aquifer rises and falls with the level of water in the river.

Water Treatment

Water usage averages approximately 1.4 mgd. Present equipment permits a maximum pumping rate of 1500 gpm with a 75,000 gallon elevated storage tank floating on the system to meet peak demands. The only treatment consists of the addition of approximately four ppm of chlorine in the form of gaseous chlorine.

Laboratory Studies

Analysis of water. - Chemical analyses of the water from two of the four wells and of a composite sample from all wells were available from Hall Laboratories in Pittsburgh, Pa. These data are shown in Table 4. Phenol was found in one of the samples, which indicated that chlorophenols might be the source of the observed tastes and odors. While the concentration of ammonia reported seemed unreasonably high for a potable water, its effect on taste and odor should obviously be included in any evaluation.

Methods. - A series of laboratory experiments were run in order to compare the action of both chlorine and iodine on synthetic waters containing known amounts of ammonia and phenol.

Water for use in evaluating each variable was prepared from demineralized water by passing it through a column of activated carbon to remove all taste and odor. Reagents added to the water were ACS reagent grade with stock solutions and subsequent dilutions prepared from taste-free water. All stock solutions and dilutions were prepared immediately prior to use.

Table 4

Chemical Analysis of Plant Water Supply
Union Carbide Corporation, Metals Division
Marietta, Ohio June 4, 1965

	Well No. 2	Well No. 6	Tap in Lab
pH value @ 25°C	7.2	7.2	7.0
Bicarbonate (HCO_3)	267	206	224
Sulfate (SO_4)	485	275	355
Chloride (Cl)	146	94	123
Nitrate (NO_3)	25	< 5	15
Silica (SiO_2)	16	12	14
Phenol	< 0.005	< 0.005	0.015
Hardness (as $CaCO_3$)	740	480	600
Calcium (Ca)	236	149	184
Magnesium (Mg)	37	26	34
Iron (Fe)	< 0.05	0.15	< 0.05
Manganese (Mn)	0.25	2.3	0.8
Sodium (Na)	82	54	68
Chromate	< 0.1	< 0.1	0.1
COD	3.6	3.0	2.7
Cr^{+3} Chromate	0.1	0.1	0.1
Potassium	11	4.4	7.6
Syndet	0.1	0.1	0.1
Suspended Solids (est)	< 5	< 5	< 5
Ammonia (NH_3)	22	3	13

Taste and odor. - The tests were conducted by selecting a taste panel and letting each member taste the water without knowing its contents. To prevent tiring of the members' taste buds the tests were conducted in two parts. Test I was designed to determine the preference of panel members for water containing phenol and treated with chlorine; with iodine released from KI by chloramine; and with iodine released from KI by chlorine (HOCl). Test II was designed to determine the preference of panel members for waters containing phenol and treated with chlorine, chloramine, elemental iodine, and elemental iodine plus ammonia. In each test taste-free water was used as a control. The results of these tests are tabulated in Tables 5, 6, 7, and 8.

These data suggest that:

1. There is a definite preference for iodinated over chlorinated water when phenol is present.
2. Taste is slightly enhanced when chlorine is used to oxidize I^- to HIO in the presence of ammonia and phenol.
3. Iodination using elemental iodine is preferred over iodination using potassium iodide plus chlorine.

Marietta, Ohio well water. - Samples of water which were shipped from Marietta, Ohio, were used in laboratory tests to determine whether iodinating the water would produce an objectionable taste. Since phenol is unstable in water[57] and since the water was en route four days, it was assumed that all phenol was gone. Therefore, phenol was added to the samples immediately prior to adding other reagents used in the test.

Taste tests using 50 ppb phenol were conducted to determine the

Table 5

Taste Test No. I. Averaged Preferences of Nine Observers

Sample No.	Preference No. (Avg)	Order of Preference	Materials added to taste-free demineralized water - ppm			
			Phenol	Ammonia	Iodide	Chlorine
1	3.1	2	.01	0	1.0	.224
2	3.67	4	.01	.1	1.0	.224
3	3.13	3	.001	0	0	.224
4	3.89	5	.01	0	0	.224
5	1.67	1	0	0	0	0

Table 6

Taste Test No. I. Individual Preferences of Nine Observers for Waters of Table 5

Sample No.	1	2	3	4	5	6	7	8	9
1	2	2	3	4	5	4	5	2	1
2	5	3	5	5	4	2	4	3	2
3	3	5	2	2	1*	3	1	5	4
4	4	4	4	3	2*	5	2	4	5
5	1	1	1	1	3	1	3	1	3

*No order stated - both alike.

Table 7

Taste Test No. II. Averaged Preferences of Eight Observers

Sample No.	Preference No. (Avg)	Order of Preference	Materials added to taste-free demineralized water - ppm			
			Phenol	Ammonia	Iodine	Chlorine
1	3.29	2	.001	0	0.8	0
2	3.72	3	.010	0	0.8	0
3	3.0	1	.010	0	0	0
4	5.0	6	0	0	0	0
5	4.0	4	.010	.1	0.8	0
6	5.6	7	.010	0	0	.224
7	4.25	5	.010	.1	0	.224

Table 8

Taste Test No. II. Individual Preferences of Eight Observers for Waters of Table 7

Sample No.	1	2	3	4	5	6	7	8
1	6	2	5	1	1	2	1^x	6
2	7	1	6	2	2	3	2^x	5
3	1^*	3	3	3	3	4	3^x	2
4	2^*	4	4	7	5^*	1	4^y	1
5	3^*	5	1	6	6^*	5^*	5^y	4
6	4^*	6	7	4	4	6^*	6^z	7
7	5^*	7	2	5	7^*	7^*	7^z	3

*No preference or all tastes the same.

^{x}1,2,3 no preference as to order but best.

^{y}4,5 no preference but intermediate.

^{z}6,7 no preference but worst.

relative effects of the two halogens. The results are tabulated in Table 9. These data suggest that iodinated water is preferred over chlorinated water. Comments expressed by the taste panel showed that each water was palatable and that a five in order of preference was still an acceptable water.

Table 9

Comparison of Taste Produced by Chlorine and Iodine in Marietta, Ohio Well Water Containing .05 ppm Phenol

Sample No.	Order of Preference	Reagents Added to Marietta, Ohio Well Water (ppm)			
		Phenol	Iodide	Iodine	Chlorine
1	5	.05	1.5		0.42
2	3	.05		1.5	
3	4	.05			0.42
4*	1	.05		1.5	
5*	2	.05			0.42

*Demineralized water used as controls.

Since no objectionable taste was observed when 50 ppb of phenol was used, it was felt that perhaps a different ratio of halogen to phenol should be used. From works published by Burttschell, Rosen, Middleton, and Ettinger[68] maximum taste is produced when the ratio of chlorine to phenol is 2:1. As reported earlier in this section, the normal dosage of chlorine is four ppm; thus, the dosage of phenol should be two ppm.

The results of taste tests using the above concentrations are shown in Table 10.

Table 10

Comparison of Taste Produced by Chlorine and Iodine in Marietta, Ohio Well Water Containing 2.0 ppm Phenol

Sample No.	Order of Preference	Reagents Added to Marietta, Ohio Well Water (ppm)		
		Phenol	Iodine	Chlorine
1*	1	2.0		
2	2	2.0		4.0
3	3	2.0	1.5	

*Demineralized water included as a reference.

All observers termed the tastes produced as extremely bad.

The results of the laboratory studies suggested that some agent other than phenol was present in the water, causing taste to develop.

Iodine demand data on the well water with and without added phenol add strength to the hypothesis that something other than phenol was responsible for the observed tastes. See Figure 2. The results obtained clearly indicated the need for similar tests on samples immediately after pumping from the wells, and arrangements were made for a trip to Marietta in order that such tests could be made.

Studies Conducted at Marietta, Ohio

Taste and odor of raw water. - Immediately after collecting water from each of the four wells, the presence of taste and odor was determined using plant personnel as panel members. Water from a private well

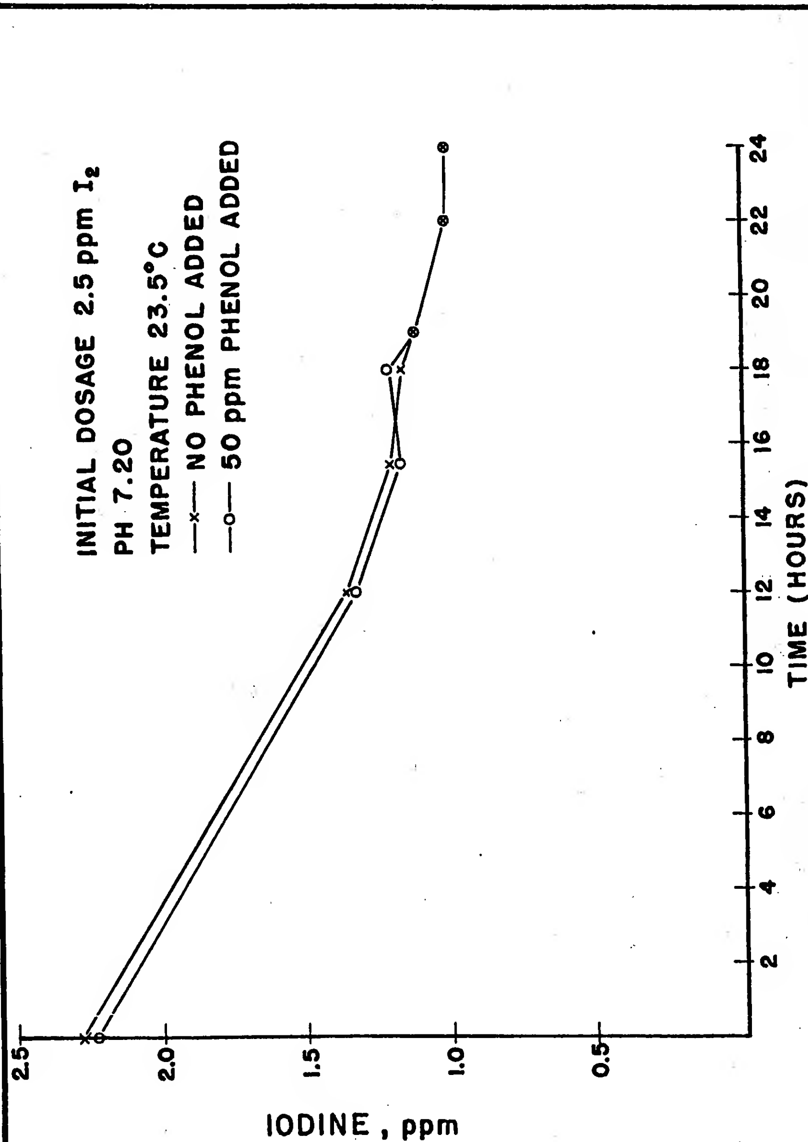


FIG. 2–IODINE DEMANDS OF MARIETTA, OHIO, WELL WATER AFTER SEVERAL DAYS STANDING

in the same aquifer and located one mile southest of the wells of primary interest was included for comparison purposes. This well is designated as "One-mile Well." The results are shown in Table 11.

Table 11

Taste and Odor of Raw Water

Well No.	Taste	Points*	Odor	Points*
2	astringent	65	none	0
3	slightly less	60	none	0
5	strongest	100	strong**	100
6	less	85	moderate**	70
Composite	intermediate	80	slight	30
One-mile Well	good	0	none	0

*Points assigned on the basis of 100 points for Well No. 5.

**Identified by R. P. Vogh as the characteristic odor of chlorobenzene.

An inspection of the chlorination equipment revealed that the water supply was not being chlorinated and had not been for several days due to a strike of operating personnel. Even without the addition of chlorine, the taste of the water was highly objectionable, so much so that no one had noted the absence of chlorine in the treated water. Even though it was apparent that nothing would be gained by iodinating the

water, it was felt that data of great value might result from efforts to determine the nature and amounts of organic materials present in the water and a comparison of its chlorine and iodine demands.

Halogen residuals. - The first test was planned to determine the persistence of low halogen residuals in water from individual wells. Wells No. 3 and No. 5 were selected, with "One-mile well" as the control. To samples of water from each of these wells was added, in one series, 4.0 ppm of chlorine; in a second series, 0.50 ppm of I_2; and in a third series, 0.50 ppm of HIO. The I_2 and HIO residuals were determined over a period of 20 hours since this portion of the test was started soon after arriving at Marietta. The chlorine residual was determined only once, at the end of three hours, as that portion of the test was not begun until late in the second day of the plant visit. The data are shown in Table 12. They show that in these waters HIO residuals were quite persistent; that free I_2 residuals disappeared quickly; and that of the three well waters, that from Well No. 5 had the greatest apparent chlorine demand. This point will be referred to again later.

These data suggest that the water contains enough ammonia to tie up all chlorine as chloramine and in addition, pollutants are present which have an iodine, HIO and chlorine demand.

Iodination of the plant water supply. - Realizing that iodination would perform no miracle, Company officials requested that the water supply be iodinated for a short period of time in order to evaluate some of the variables involved.

Table 12

I_2, HIO, and Cl_2 Residuals in Raw Water

Well No.	Cl_2 (ppm)	I_2 (ppm)			HIO (ppm)		
	3 hr.	3 hr.	8 hr.	20 hr.	3 hr.	8 hr.	20 hr.
3	3.73*	0	0	0	0.48	0.48	0.27
5	1.76*	0	0	0	0.15	0.14	0.07
One-mile Well	3.85**	0.48	0.46	0.30	0.53	0.51	0.45
Initial Concen.	4.0	0.50			0.50		

*Combined chlorine.

**Free chlorine.

Iodine was fed into the system as a solution of potassium iodide, using an automatic proportioning, hydraulically driven Wallace and Tiernan hypochlorinator. The strength of the potassium iodide solution fed was adjusted to one pound per gallon. Gaseous chlorine fed by the existing chlorinator was used to oxidize the iodide ion to HIO. The exact feed of chlorine could not be determined since the rotometer was not accurately calibrated below ten pounds per 24 hours.

A check of the residual in the distribution system showed that a residual of 0.17 ppm (HIO) was maintained to the administration and laboratory building.

Additional laboratory studies. - Additional laboratory studies were initiated in an effort to determine more about the taste and odor present in the water. Two methods of treatment which were used to shed light on the nature of the agents are:

1. Superchlorination to oxidize the organic material.
2. Aeration to remove gaseous components.

Superchlorination. - A composite sample of water was dosed with 10, 20, 40, 60, and 120 ppm of Cl_2 in an effort to oxidize the organic matter present in the water. While the odor and taste of chlorine were pronounced, the odor and taste present in the raw water were either considerably reduced or masked by the chlorine. A yellow color appeared in the water containing greater than 20 ppm chlorine and a brown precipitate formed when samples were allowed to stand for from two to four hours. Chromate and chlorinated organics are possible sources of the color, but the presence of neither of these has been confirmed. It is also possible for diaminobenzene or related compounds to produce a yellow color when oxidized by chlorine.[69] This is similar to the orthotolidine test for chlorine.[70]

Aeration. - A composite sample of water was aerated for three hours by bubbling air through the water at the rate of 75 bubbles per minute. If the water prior to aeration was assigned a taste rating of 100, the aerated water would be rated at 20.

The results obtained after adding Cl_2, I_2, and HIO to the aerated water are tabulated in Table 13.

Table 13

Taste of Aerated Samples Treated with Cl_2, I_2 and HIO

Dosage	Taste in One Hour	Order of Preference
4.0 ppm Cl_2	Not objectionable	3
0.5 ppm I_2	Not objectionable	2
0.5 ppm HIO	Not objectionable	1

Ammonia and COD. - The ammonia content of water from each well was determined by Kjeldahl distillation.[57] As shown in Table 14, some extremely high values were obtained.

Table 14

Observed and Calculated Oxygen Demands of Several Waters

Parts Per Million of Determined Criterion	Well No.2	Well No.3	Well No.5	Well No.6	Composite Sample From Four Wells	"One-Mile Well"	Demineralized Water Plus 27 ppm NH_3-N	Demineralized Water Plus 112 ppm NH_3-N
Ammonia Nitrogen	80	112	0.38	27	54	0.04	---	---
COD	17	8.7	4.2	4.4	4.5	2.8	4.7	14

While it was realized that aromatic hydrocarbons, pyridine and ammonia would not be oxidized by dichromate to an appreciable extent, it was felt that COD data would be beneficial in determining the presence of other organics in the plant water supply.[71] From Table 14 it will be noted that the higher COD values were obtained on waters having a high concentration of ammonia. Water from "One-mile well" and demineralized water containing a known concentration of ammonia were included for comparison purposes.

These data suggest that ammonia was responsible for most of the observed COD and further suggest that if organics which are oxidizable by dichromate were present in the water, they were present in relatively low concentrations.

Halogen demands. - Halogen demand was determined by adding sufficient halogen to yield the desired initial concentration and immediately determining the halogen residual. This initial halogen concentration was increased until a measurable free residual was obtained. The chlorine and iodine demands of the waters are tabulated in Table 15 and presented graphically in Figure 3. The calculated chlorine demand of each water based on its ammonia content and the following equation are shown in Table 15.

$$2NH_3 + Cl_2 \rightarrow 6HCl + N_2$$

As previously mentioned, data which are presented in Table 12 show that water from well No. 5 had a higher chlorine demand than that from well No. 3 and "One-mile well." Quite a different conclusion must

Table 15

Calculated and Observed Halogen Demands of Water from Five Wells at Marietta, Ohio

Sample	Chlorine Demand, ppm		Measured Iodine Demand, ppm*	
	Calculated	Observed	As I_2	As HIO
Well No. 2	607	806	0.07	0.11
Well No. 3	850	1179	0.07	0.12
Well No. 5	2.8	4.2	1.66	0.57
Well No. 6	207	221	1.32	0.36
Composite**	410	490	0.82	0.26
"One-mile well"	0.33	1.0	0.03	0.05

*Dosage yielding measurable free halogen residual within five minutes.

**Composite sample prepared by mixing equal volumes of water from each of the four plant wells.

be drawn, however, when the results shown in Table 15 are considered.

It is interesting to note that the iodine demands are quite different from those for chlorine, not only in magnitude but in relative demands as well. While well No. 5 has a relatively low chlorine demand it has the highest HIO and I_2 demand. These data show that while much of the chlorine demand can be accounted for from the ammonia content of the water, other pollutants are present which also have a chlorine demand. These data further suggest that either the pollutants which are present

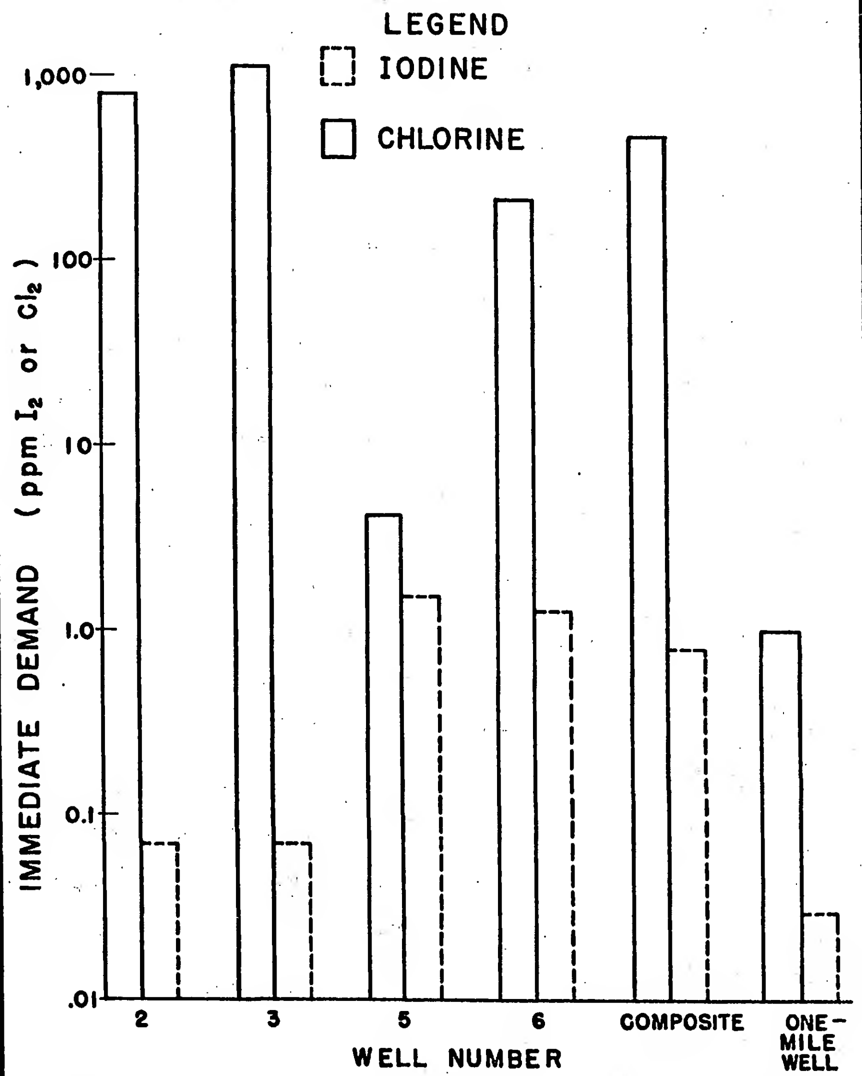


FIG. 3 – IMMEDIATE CHLORINE & IODINE DEMANDS OF MARIETTA, OHIO, WELL WATER OCT. 7, 1966

in wells No. 5 and No. 6 are different than those found in wells No. 2 and No. 3, or the high concentration of ammonia or other pollutants present in wells No. 2 and No. 3 inhibit the reaction of I_2 and HIO with certain pollutants which would otherwise show an I_2 and HIO demand.

Possible Pollutants

A brief survey of the plant's waste disposal practices was made in an effort to gather more information regarding possible pollutants. A Union Carbide plant operated by its Plastics Division is located adjacent to the plant operated by its Mine and Metals Division. It was disclosed that phenol and styrene monomer are produced from chlorobenzene in the plastics plant. The principal waste products of the plant are tars which are disposed of in a waste disposal area located uphill from the well field. Some chlorobenzene, phenol and styrene monomer are contained in the tars and are necessarily dumped in the waste disposal area along with the tars. Since chlorobenzene and phenol are solvents and miscible with water, it is highly probable that a mixture of these waste products finds its way into the aquifer and well field.

This limited survey of waste products is obviously incomplete since an analysis of the water shows a high concentration of ammonia in most of the wells. Company officials gave no indication as to the source of ammonia.

Summary and Conclusions

As indicated by preliminary laboratory studies, iodination of a Marietta, Ohio, well water without preliminary aeration did not produce a palatable water. While the presence of phenol in the raw water was

believed to be responsible for the taste in the treated water, there are several indications that it is not the sole source of taste and odor. Three observations which lead to this conclusion are:

1. The raw water, before treatment, has an objectionable taste and odor. The odor has been identified as the characteristic odor of chlorobenzene which is one of the raw materials used in the production of phenol.

2. Even though the water supply had not been chlorinated for several days due to a strike of operating personnel, plant personnel had detected no difference in the taste of the water.

3. With ammonia present in the raw water, all chlorine exists as chloramine which would be expected to react too slowly with phenol to cause an appreciable buildup of chlorophenols during the very short time which the water remains in the distribution system.[72]

The COD of the raw water suggests that the major contaminants are aromatic hydrocarbons and ammonia. Both chemical analyses and a knowledge of the plant's waste products substantiate this hypothesis.

While aeration and subsequent disinfection of the raw water produced a water having an acceptable taste, it was recommended that another source of water be obtained before iodinating the supply on a continuous basis.

The work done toward iodinating this water supply has been of great value in demonstrating the potential which iodine has as a disinfectant for water. It has clearly demonstrated that a low HIO residual can be maintained in the presence of high concentrations of ammonia and

other industrial pollutants as had been predicted from the chemical properties of iodine.[73]

Gainesville Study

Floridan Aquifer

General characteristics. - The City of Gainesville is located over one of the most productive ground water formations in the continental United States. This formation, called the Floridan Aquifer, underlies most of the Florida peninsula with numerous recharge areas and sufficient head to prevent serious salt water intrusion.[74] It is the primary source of fresh water for Florida and serves as the source of water supply for most municipalities. This aquifer is the source of water supply for the City of Gainesville.

In the Gainesville area, the Floridan Aquifer is composed primarily of limestones and dolomites to a depth of several thousand feet. The cover of sands and clays extends from the surface to a depth of about 150 feet,becoming thinner to the southwest and thicker to the northeast.[65]

Characteristics in the Gainesville area. - Well drillers' logs show that the characteristics of the FloridanAquifer in the Gainesville area are substantially the same as those encountered in the City of Gainesville well No. 4. These characteristics are as follows:[46]

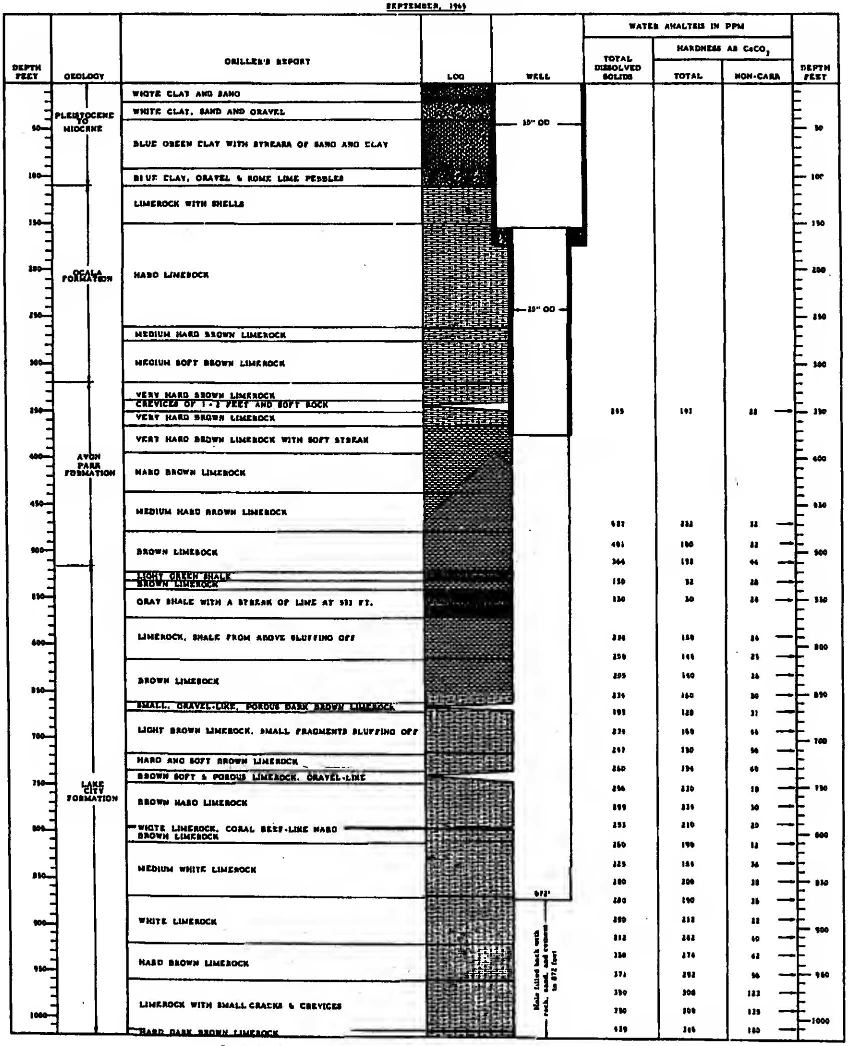
1. The aquifer begins at approximately 100 to 150 feet in depth.
2. It extends beyond 1,020 feet in depth.
3. The permeability of the aquifer varies considerably due to the presence of several beds of permeable, cavernous limestone separated by other beds of practically impermeable limestones

and dolomites.

4. The most cavernous and porous beds are found between 100 and 200 feet and at 300 to 350 feet.
5. Relatively permeable beds are again found between 650 to 800 feet and from 960 to at least 1,020 feet.
6. Between 350 and 650 feet there are layers of practically impervious limestones and dolomites which, at least in the Gainesville area, impede direct communication between the upper and lower permeable beds.
7. The water in the upper part of the aquifer is moderately hard (200 ppm as $CaCO_3$), low in chlorides (10 ppm as Cl), and low in sulfates (15 ppm as $SO_4^=$). The quality of the water derived from these strata remained relatively constant until recent years, when a notable deterioration in quality has been observed. Pollution from surface water and sewage has become increasingly evident, especially during periods of heavy rainfall.
8. Water in the lower part of the aquifer (650 to 850 feet) is slightly harder (226 ppm as $CaCO_3$) and slightly higher in sulfates (84 ppm as $SO_4^=$). So far this stratum has remained relatively uncontaminated.
9. Water from a still deeper part of the aquifer (1,015 feet) is even harder (346 ppm as $CaCO_3$) with a noncarbonate hardness of 180 ppm as $CaCO_3$.

Figure 4 is a graphical representation of geological characteristics

SUMMARY OF INFORMATION FROM WATER SUPPLY WELL NO. 4
CITY OF GAINESVILLE FLORIDA
SEPTEMBER, 1965



WATER PRODUCTION DATA	Depth in Feet From	Depth in Feet To	Specific Yield gpm/foot	REMARKS
	373	872	110	Original well
	373	465	2	Tested with bailer
	372	550	3	Estimated during drilling
	373	880	19	Pump tested 1200 gpm with 63 ft. drawdown
	372	1020	27	Pump tested 1600 gpm with 60 ft. drawdown
	373	872	62	Pump tested 3800 gpm with 66 ft. drawdown. (After acidizing with 6000 gallons HCl.)

Fig. 4 - (Reference 46)

and water quality in the Floridan Aquifer as derived from data obtained during drilling and testing city well No. 4.[46,65]

It should be noted that the aquifer can be considered as being primarily composed of three strata as follows:

1. An upper permeable stratum extending from 100 feet to approximately 350 feet in which cracks, crevices and caverns are numerous.
2. An impervious stratum between 350 and 650 feet.
3. A lower permeable stratum beginning at about 650 feet and extending to about 800 feet.

Piezometric Surface and Flow of Ground Water

A hydrological study of a four-county area which included Alachua County was conducted by the Florida Geological Survey in 1958-1960.[75] The piezometric levels in the upper permeable stratum of the Floridan Aquifer in the Gainesville area were redetermined in August, 1965, and found to be six to eight feet higher than at the same points in 1960.[46] The higher elevations were probably due to heavy rains during June, July, and August, 1965.[46] Substantially the same gradients were found in August, 1965, indicating that the direction of underground water movement remains the same regardless of whether the piezometric level rises or falls.

Figure 5 shows the contours of the piezometric surface in the top part of the Floridan Aquifer as of August, 1965, as well as pertinent points for future reference. These contours suggest that:

1. Ground water flows from a wide area around Gainesville to the

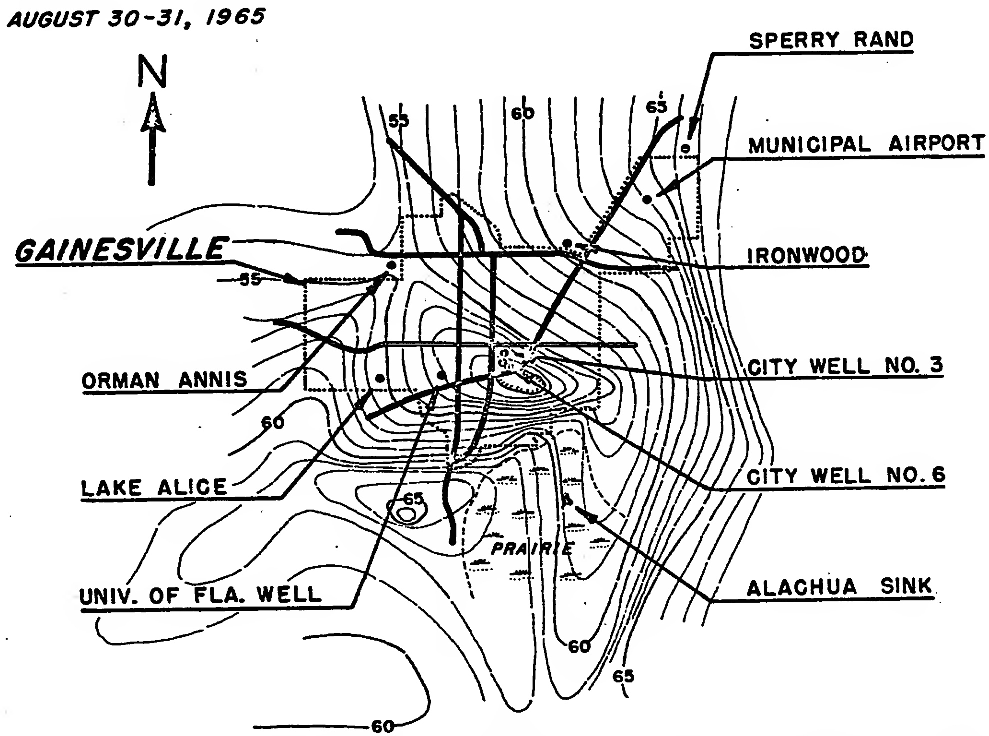


Fig. 5 - **CONTOURS OF THE PIEZOMETRIC SURFACE IN THE TOP PART OF THE FLORIDAN AQUIFER AND RELATIVE LOCATION OF SAMPLE POINTS**

city's well field which is located in the southeast section of the city.

2. East of Gainesville water flows from east-northeast to west toward Gainesville.

3. To the west and north ground water flows from southeast to northwest.

Very few wells in the Gainesville area penetrate both the upper and lower permeable strata and even fewer penetrate the lower permeable stratum with the upper stratum cased out. Without the upper stratum cased out it would be difficult if not impossible to determine the piezometric level of water in the lower permeable stratum. City well No. 6, however, penetrates both the upper and lower permeable strata with the upper permeable stratum cased out. Measurements made on city well No. 6 over a three-year period include the random measurement of the piezometric level of water in both the upper and lower permeable strata. These data, which are tabulated in Table 16, show that the water level in the upper permeable stratum is higher than that in the lower stratum.[46,76] These results indicate that there will be a downward flow of water from the upper to the lower stratum where connections between the two strata exist.

Pollution of Aquifer

Source of water. - The source of water for the City of Gainesville is a series of seven wells located near the water treatment plant in the southeast section of the city. While all wells penetrate the Floridan Aquifer, depths of the wells vary from 365 feet to 872 feet; thus, the

Table 16

Level of Water in the Upper and Lower Strata of the Floridan Aquifer. Well No. 6, City of Gainesville

Depth From Surface to Water Level (feet)	Aug. 26, 1964	Oct. 29, 1964	Aug. 31, 1965	Apr. 25, 1967
Lower stratum	87.9	85.1	86.2	86.4
Upper stratum	86.8	84.3	81.3	86.0
Difference	1.1	0.8	4.9	0.4

water obtained from each well may have different characteristics, depending on the depth from which the water is obtained. The physical characteristics of these wells are summarized in Table 17 and the chemical characteristics in Table 18.

In time, well No. 1 was turned over to the City of Gainesville Power Plant for use as a source of cooling water. Wells No. 2 and No. 3 are old wells with antiquated equipment, showing evidence of pollution, and are not in regular use.

Evidence of pollution. - Until recent years (prior to 1960) wells No. 4, No. 5, No. 6, and No. 7 produced water of good quality. About 1960, wells No. 4 and No. 6 began to show an increase in color and bacteriological count during periods of high rainfall.[46]

In November, 1963, the quality of water in wells No. 4 and No. 6

Table 17

Characteristics of Wells from Which Water for the City of Gainesville Is Obtained

Well No.	Total Depth (ft)	Casing Dia. (in)	Casing Depth (ft)	Yield gpm	Draw-down (ft)	Remarks
1	365	12	266	1200	5	Old well, abandoned
2	407	18	128	1800	16	Not in regular use
3	421	18	170	2000	1	Not in regular use
4	464	30	173	5100	7	Polluted. Had to be relined and deepened
4	872	20	375	3800	46	Relined and deepened
5	742	24	152	4300	13	Needs to be relined
6	750	24	163	4000	12	Polluted. Had to be relined
6	750	20	331	2800	46	Relined
7	713	24	157	3500	3	Needs to be relined

deteriorated rapidly, reaching a peak in January, 1964, after several days of abnormally high rainfall which had been preceded by several months of very dry weather.[75] The presence of high organic color (150 units), high coliform counts (100+) and a high concentration of detergents in well No. 6 suggested the presence of sewage pollution. A blanket of detergent foam several feet thick, produced by recarbonation of the treated water passing to the filters is shown earlier in this study in Figure 1.

Table 18

Chemical Characteristics of Water from Wells in the City Well Field, March, 1967

Constituent	Well No.2	Well No.3	Well No.4	Well No.5	Well No.6	Well No.7
	Parts Per Million					
Total dissolved solids	277	195	309	248	331	280
Total hardness, as $CaCO_3$	212	178	256	180	266	200
Carbonate hardness, as $CaCO_3$	173	80	202	152	192	166
Noncarbonate hardness, as $CaCO_3$	39	98	54	28	74	34
Alkalinity, as $CaCO_3$	173	79	202	152	192	166
Calcium, as $CaCO_3$	139	127	184	120	190	140
Magnesium, as $CaCO_3$	73	51	72	60	76	60
Chlorides, as Cl	11	11	8	13	12	12
Iodides, as I	9.5	11.4	12.0	7.0	15.5	12.4
Sulfates, as $SO_4^=$	13	5	50	8	84	24
Organic Color (units)	10	27	3	37	7	20
pH (units)	7.60	6.90	7.52	7.55	7.4	7.50

<u>Possible sources of pollution</u>. - Two possible sources of sewage pollution existed on the periphery of the city; (1) the effluent from the university sewage treatment plant as well as wastes from the Teaching Hospital which at that time emptied into a sink hole on the University of Florida campus, and (2) effluent from the city's sewage treatment facility which eventually enters Alachua Sink via Sweet Water Branch. Both of these sinks are located approximately three miles from the city's well field, Alachua Sink to the south and the sink on the University of Florida campus to the west.

On four occasions prior to 1964, the effluent of the University of Florida Sewage Treatment Plant had been traced through the sink on the University of Florida campus to the city well field.[75] An isotope spill at the University of Florida Teaching Hospital in August, 1962, provided an excellent tracer to show that water entering the sink reached the city's water treatment plant in less than ten hours, which means that the water traveled the straight-line distance of approximately 9,500 feet at a minimum velocity of 16 feet per minute.[76]

After the evidence of sewage pollution in city well No. 6 in January, 1964, the University of Florida diverted the sewage effluent from the sink into Lake Alice and sealed off the sink. Lake Alice, however, is drained by two drainage wells located at the west end of the lake. Both of these drainage wells penetrate the upper permeable stratum of the Floridan Aquifer as may be seen from Table 19.

Dye tests conducted by adding 25 pounds of Rhodamine-B dye in the west drainage well at Lake Alice in January, 1964, failed to show any

Table 19

Drainage Wells at West End of Lake Alice

	Well No. 1	Well No. 2
Total depth, feet	235	450
Casing diameter, inches	24	24 - 20
Casing depth, feet	83	243

connection between the drainage wells and the city's well field.

Likewise, the addition of 20 pounds of Uranine-B dye into Alachua Sink failed to positively show a direct connection between the sink and the city well field. Samples of water collected from well No. 6 after dye was added to the sink were analyzed by two different laboratories using three different methods. The results were conflicting so that no definite conclusion could be drawn. The addition of 50 pounds of Rhodamine-B dye to Haile Sink, a straight-line distance of 29,400 feet from city well No. 6, likewise failed to show a connection between the sink and the city well field. The results, however, are not surprising since the dyes used in these tests have been shown to have a rapid photochemical decay.[77] Organic color, almost always present, fluoresces brilliantly, and some of the materials present in treated sewage are known to be fluorescent.[78]

Samples of water were collected from the various sinks and surface

waters in the area in an effort to use a comparison of nematode and algae forms as indicators of the source of pollutants. Professor W. T. Calaway of the University of Florida Department of Entomology reported that while the algae forms in Lake Alice and Alachua Sink were different, no definite conclusions could be drawn regarding the source of pollutants in the city wells.[76]

In brief, after the sink hole on the University of Florida campus was sealed off and effluent from the campus sewage treatment facility and Teaching Hospital diverted to Lake Alice, no direct connection between known sources of sewage pollution and the city's well field could be proven.

Hydrological investigation. - Hydrological investigations were made in wells No. 4 and No. 6 in order to determine the point of entry of the polluted water. These investigations consisted of:[46]

1. Electric logging.
2. Temperature logging.
3. Depth sampling.
4. Deep well current meter traversing.

The results showed that the polluted water was entering each well from the lower portion of the upper permeable stratum of the Floridan Aquifer.

Corrective measures. - Polluted water was prevented from entering these two wells by relining well No. 6 to a depth of 331 feet and deepening well No. 4 to 872 feet and relining it to a depth of 375 feet. Essentially the stratum from which the polluted water was entering the

wells was cased out so that water pumped from these two wells entered the well from the lower permeable stratum.

While the problem of grossly polluted water entering the city's wells has been somewhat relieved, polluted water still persists in the upper permeable stratum.

Threat of additional pollution. - Apparently both Alachua Sink and the drainage wells at Lake Alice penetrate only the upper permeable stratum. In the absence of cracks, crevices or other means of communication between the upper and lower strata, the lower stratum should continue to provide a supply of good quality water. However, a potential threat to the lower stratum exists on the campus of the University of Florida as described below.

The University of Florida has three deep wells for use in connection with its steam and air conditioning plant. These wells are located immediately west of the Teaching Hospital and approximately 1.5 miles west of the city's wells. As shown in Table 20, these wells penetrate the lower permeable stratum and are open to both the upper and lower strata. Tests conducted in the city's wells show that water is preferentially pumped from the upper stratum even though a well may penetrate both. These wells thus present a serious potential route for polluted water to enter the lower stratum.

Table 20

Characteristics of Three Wells Owned by the University of Florida

	U. S. Geological Survey No.		
	938-221-1	938-221-2	938-221-3
Total depth, feet	916	700	909
Casing diameter, inches	20	20	24
Casing depth, feet	290	188	183

Selection of Sample Points

Sample points were selected to establish the baseline iodide concentration in the water prior to the possible initiation of iodination of the city's water supply and to determine the source and extent of sewage pollution in the Floridan Aquifer near the City of Gainesville. The locations of sample points are given in Table 21 and represented graphically in Figure 6. Samples of water entering the ground at Alachua Sink and the drainage wells at Lake Alice were included to show the quality of water entering the ground at these points.

From Table 22 one may observe that the wells which were selected are pumped frequently if not continuously and at a rate much greater than the usual home owners' well. These wells should serve as an excellent source of water representative of water in the aquifer in that particular area.

Table 21

Location of Sample Points

Number	Name or Identification	Location
1	City well No. 3	605 SE 3rd Street
2	City well No. 6	Approx. 800 SE 5th Street
3	University of Florida	West of Teaching Hospital on Archer Road
4	Ormon Annis properties	29th Place at NW 22nd Street
5	Sperry Rand Corp.	Waldo Road
6	Municipal Airport	Waldo Road
7	West drainage well at Lake Alice	Univ. of Florida campus
8	Alachua Sink	Camp Ranch SE of 41st Avenue and 15th Street SE

The wells at Sperry Rand Corp. and the Municipal Airport were selected not only for their geographic location with respect to the city wells but should be representative of wells which will comprise the city's new well field to be located in that area.

The University of Florida well was selected partially because of its geographic location but primarily because of its possible role in providing a route for pollutants to enter the lower permeable stratum from the upper stratum.

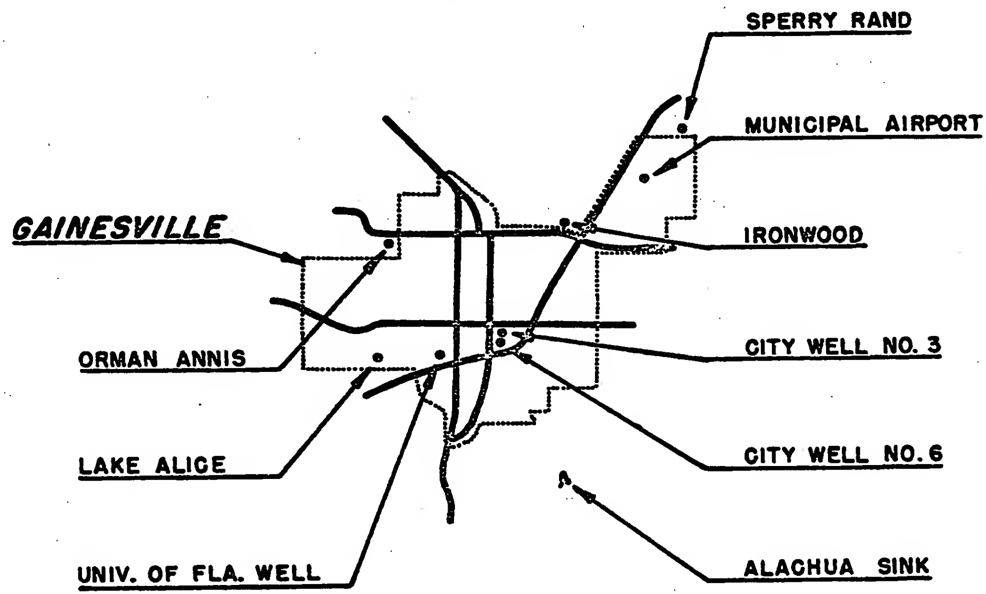


Fig. 6 - Relative Location of Sample Points

Table 22

Pertinent Data Relative to Sampling Points

No.	Name or Identification	Total Depth (ft)	Casing Depth (ft)	Casing Diameter (in)	Pumping Rate or Flow(mgd)	Frequency of Pumping or Flow
1	City well No. 3	421	170	18	2.9	As needed
2	City well No. 6	750	331	24 - 20	4.0	Frequently
3	Univ. of Fla.	909	183	24	2.5	Continuously
4	Ormon Annis	330	175	6	0.3	As needed
5	Sperry Rand Corp.	350	160	12	0.72	Continuously
6	Municipal Airport	447	175	10	Unknown	Frequently
7	Drainage well at Lake Alice	235	83	24	4.2*	Continuously
8	Alachua Sink	--	--	--	40.0*	Continuously

*Average of three flow checks made by using an electric current meter manufactured by W. and L. E. Gurley Co., Troy, N. Y.

In the northwest section of the city, wells which were pumped continuously could not be found. Instead, several wells were available whose primary use is as a source of water supply for a small residential area. The south well located on Orman Annis' property was selected because of accessibility and the amount of data available on this well.[46,75]

While it would have been desirable to sample each well used as a source of supply for the City of Gainesville, it was felt that perhaps

typical wells could be used to obtain the same information. City well No. 3 was selected as a typical well extending only into the upper permeable stratum of the Floridan Aquifer, while well No. 6 was selected as a typical well extending into the lower stratum with the upper stratum cased out. Henceforth in this study wells owned by the City of Gainesville will be referred to as well No. 3 or well No. 6., etc.

Description of Water Treatment Facilities and Distribution System

The water treatment plant is designed for lime-soda softening of the water. Facilities include two upflow solids-contact units, recarbonation, rapid sand gravity filters, and chlorination. Raw water is pumped directly into the solids-contact unit where the sludge, activated silica and lime slurry are thoroughly mixed. The softened water is separated from the sludge in the clarification zone and then passes by gravity through the recarbonation basin where the pH is reduced from pH 10.3 to its stabilization pH of about 8.6. The stabilized water is filtered through six rapid sand gravity filters into a 200,000 gallon clear well, and subsequently transferred to either a 500,000 or a 1,000,000 gallon ground storage reservoir.

Excess sludge is processed in a vertical Fluosolids calciner or dewatered in a centrifuge for disposal. The treatment capacity of the solids-contact units is 15 mgd with filter capacity rated at 13.5 mgd at a loading rate of three gpm per square foot. The entire plant will process water at a maximum rate of 15 mgd.

The water is chlorinated by the addition of from 9-12 ppm of chlorine to the solids-contact unit. Ammonium sulfate is added to the

softened water to provide a chloramine residual of at least two parts per million leaving the plant.

The distribution system consists of about 185 miles of mains greater than four inches in diameter. High service pumps deliver water from the ground storage reservoir into the distribution system with two elevated storage tanks, having a total capacity of 1.5 million gallons, floating on the system.

Methods of Iodination

Data available show that accidents do happen in public water supplies which result in explosive outbreaks of disease. They frequently affect large proportions of a population with cases numbering in the thousands.[79]

Highly polluted water used as a source of water supply may likewise cause widespread disease. The outbreak of infectious hepatitis which occurred in Delhi, India, in 1955-56, is a classic example of a viral disease outbreak occurring when conventional treatment produced a water meeting the bacteriological criteria of the USPHS Drinking Water Standards. The low chloramine residual which was maintained in the distribution system was evidently effective in producing a bacteriologically safe water but was ineffective against the virus of infectious hepatitis.[8]

The addition of ammonium sulfate to the treated water in the Gainesville plant, which converts the free chlorine present during treatment to combined chlorine, is not through choice but through necessity. It is realized that this conversion from the more active to the relatively

inactive form of chlorine very greatly reduces the bactericidal effectiveness of the element, but experience has shown that consumers will not tolerate the very pronounced tastes and odors produced when a free chlorine residual is added. It was hoped that the relatively low chemical reactivity of iodine might make it possible to maintain an iodine residual throughout the distribution system without the production of tastes and odors, and thus provide an additional factor of safety by possibly inactivating viruses which may be present in the treated water.

Iodine might possibly be added to a municipal water supply by any of the following procedures.

1. By vaporizing through accurately controlled heat input.
2. In the form of a saturated solution prepared by slowly passing water through a bed of crystalline iodine, as is being done at the Lowell institutions.
3. To employ an excess of an oxidant such as chloramine to oxidize the iodide ion (I^{-1}) to HIO. This procedure would obviously take full advantage of the principle of reoxidation and reuse, within the time and geometry limits of the distribution system.

The first two methods are more applicable to iodination when iodine alone is to be added to the supply, that is, when iodine is to be used to replace chlorine as the disinfectant. The third method, however, has many possibilities. Studies of the iodination of swimming pool water have shown that when I^{+1} reacts with oxidizable matter in water, much of the I^{+1} is reduced to I^{-1} which, in the presence of excess oxidant, will

be reoxidized to I^{+1}.[67] Calculations have been made which show that in swimming pool water the iodide ion is used as many as 13 times before it is eliminated from the pool by all types of loss.[14] It seems reasonable that by maintaining a chloramine residual in the distribution system the iodide ion would be immediately reoxidized should it be reduced by oxidizable matter in the water. Laboratory studies which will be presented later in this report confirm the assumption that a low iodine residual can be maintained for a long period of time in the presence of chloramines.

By using the last method both excess chloramine and iodine (as HIO) would be present in the water to provide a combined disinfecting action. This method has the further advantage of satisfying most of the halogen demand of the water with less expensive chlorine, thus minimizing the dosage of iodide ion required in order to maintain an HIO residual for a sufficient length of time for water to reach the ends of the distribution system. This last method was chosen as the method to be used in a brief trial run in the Gainesville water supply.

IV. MATERIALS AND PROCEDURES

General. - The analyses to be made on samples collected from each sampling point were carefully selected to give meaningful information on water quality. At the beginning of the test period, 28 different determinations were made on each sample. However, a review of the data revealed that several of the determinations could be omitted without limiting the objectives of the study, as may be seen in Table 23.

The materials and procedures used for each analysis are described in the following paragraphs. Unless otherwise specified, all analyses were as given in the 12th edition of Standard Methods for the Examination of Water and Wastewater.[57] All reagents used in this study were ACS reagent grade.

When photometric measurements were necessary, a Beckman* Model B Spectrophotometer was used.

pH. - All pH measurements were made with a Beckman** Model G pH Meter.

Free NH_3-N and organic NH_3-N. - Both free and organic ammonia-N were determined on the same sample. Free ammonia was determined by method A (distillation method) and organic ammonia by Kjeldahl digestion and distillation.

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*Manufactured by Beckman Instruments, Inc., South Pasadena, Calif.

**Manufactured by Beckman Instruments, Inc., Fullerton, Calif.

Table 23

Analytical Data Sheet

Sample #_____ Location_______________ Date: From _______ to _______

Date & time begin _______________; end_______________ No. of hours___

Meter reading begin _______________; end _______________

Pumping rate or flow of stream _______________

Analysis	Result	Analysis	Result
pH	_______	CAE	_______
COD*	_______	CCE	_______
Free NH_3-N	_______	Ether insolubles*	_______
Organic NH_3-N	_______	Water solubles*	_______
Nitrite	_______	Neutrals*	_______
Nitrate	_______	Weak acids*	_______
Iodide	_______	Strong acids*	_______
Turbidity*	_______	Bases*	_______
H_2S*	_______	Total	_______
Alkalinity*	_______	Bacteriology	
Total hardness*	_______	MFT (coliform)/100 ml	_______
Chloride	_______	MFT (non c.)/100 ml	_______
Organic color	_______	SPC colonies/ml	_______
ABS*	_______		
Phosphate	_______		
Halogen demands			
Cl_3	_______	I_2*	_______

*After evaluation of the initial data these analyses were discontinued.

Nitrate-N. - Nitrate-N was determined by method B (brucine-sulfanilic acid).

Hydrogen sulfide. - Hydrogen sulfide was determined as total sulfide (H_2S + HS^-) by method A (titrimetric method).

Chloride. - Chloride was determined by method A (argentometric method). The interference from hydrogen sulfide was eliminated when its presence was detected by odor.

Organic color. - Color was determined using a Hellige Aqua Tester* Model 611.

Alkylbenzene sulfonate (ABS) and linear alkylate sulfonate (LAS). - ABS and LAS were determined as total anionic detergents using the methyl green method described by Moore and Kolbeson.[80] The method is simple and much more applicable to a large number of samples than other methods.

Phosphate. - Phosphates were determined by the stannous chloride method which is described in Standard Methods with minor modifications to speed up the oxidation and hydrolysis of organic bound phosphorous.[81]

Halogen demands. - For the purpose of this study halogen demand is defined as the initial concentration of the halogen (either chlorine or iodine) which is necessary to give a 1 ppm free residual at the end of 24 hours.

Stock solutions of chlorine and iodine were prepared and standardized by phenylarseneoxide** titration using a Wallace and Tiernan

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*Manufactured by Hellige, Inc., Long Island City, N. Y.

**Standard phenylarseneoxide solution, 1 ml = 0.2 mg available Cl. W. H. Curtin Co., Jacksonville, Fla.

Amperometric Titrator.*

Samples of water were collected in acid-washed glass bottles and the demand studies were set up within a few hours after sample collection. Two-liter samples were placed in acid-washed glass bottles. Measured dosages of iodine or chlorine were added and the solutions thoroughly mixed and stored in a closed cabinet out of contact with light except during brief periods of sample withdrawal. Two-hundred milliliter samples were withdrawn at predetermined time intervals and halogen residuals determined by amperometric titration, using a titrator which had previously been sensitized to the halogen for which a titration was to be made. Samples containing hydrogen sulfide were aerated for one hour prior to setting up the demand study. Halogen demands determined in this manner gave a better indication of the organic content of the water than could have been obtained with hydrogen sulfide present.

Carbon chloroform extract (CCE) and carbon alcohol extract (CAE). - Both the materials and methods used for CCE determinations were as described in Standard Methods[57] except for one additional piece of equipment which is described below. CAE was determined as per instructions in USPHS Publication No. 1241.[52]

The presence of hydrogen sulfide in water posed a problem. Its presence in concentrations much higher than those of the organics would most likely cause fouling of the activated carbon long before the desired volume of water had passed through the carbon absorption unit.

*Manufactured by the Wallace and Tiernan Co., Belleville, N. J.

Its presence could also reduce the efficiency of the absorption unit by being preferentially adsorbed.

Personal communications with Dr. Breidenbach[82] of the Federal Water Pollution Control Administration at Cincinnati, Ohio, revealed that no effort was made to remove hydrogen sulfide from water sampled routinely by the National Water Quality Network. However, crystalline sulfur was frequently observed in the CCE.

The results of laboratory studies quickly revealed that when water containing hydrogen sulfide was passed through a bed of clean copper turnings the hydrogen sulfide concentration was reduced to a very low level due to the formation of insoluble CuS. Data which are presented in Figure 7 show the results which were obtained over a period of 23 days of continuous service using a small glass column filled with copper turnings. Calculations based on these data showed that a column four inches by five feet should provide sufficient contact surface to remove H_2S from approximately 2400 gallons of water.

Sections of PVC pipe four inches by five feet filled with copper wire were similarly tested for H_2S removal. The results which are given in Figure 8 show that by using four columns in series, at least 24 hours of operation could be obtained before the column required cleaning. These data suggest that the surface area of the copper wire in the pipe was considerably less than had been predicted. The copper was easily cleaned with a 25 percent solution of nitric acid and reused.

As a result of these experiments four pieces of PVC pipe four inches by five feet filled with copper wire were placed in the line

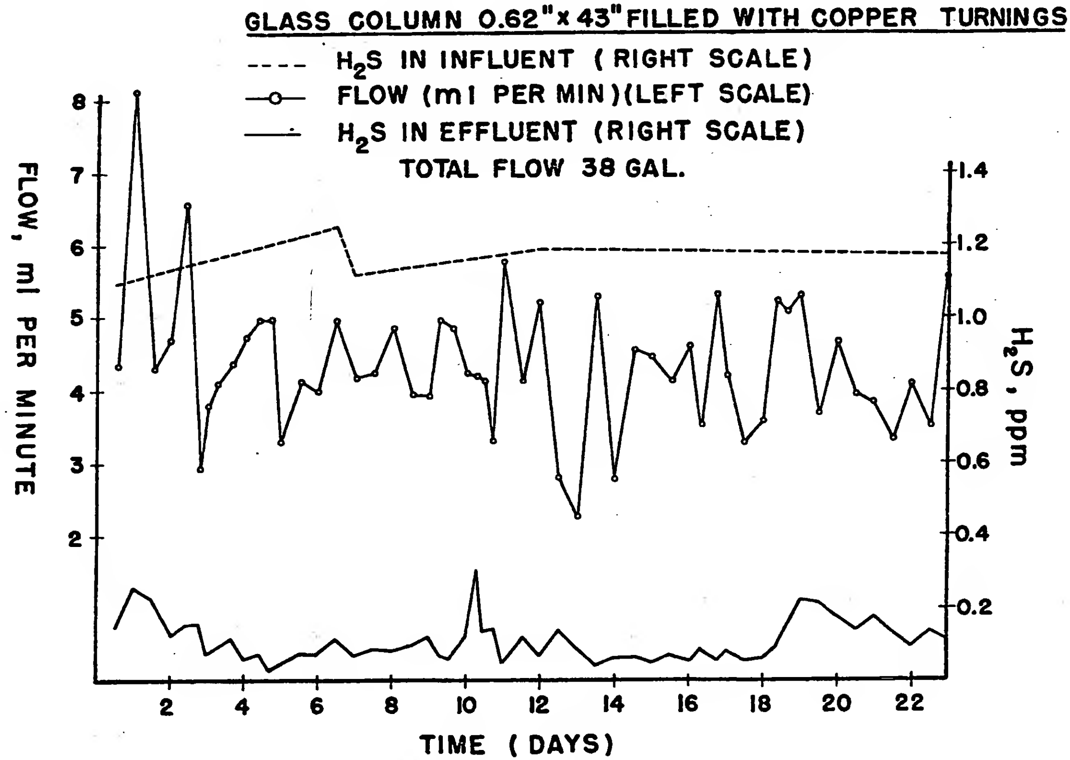

FIG. 7 - REMOVAL OF H_2S FROM WATER WITH COPPER TURNINGS

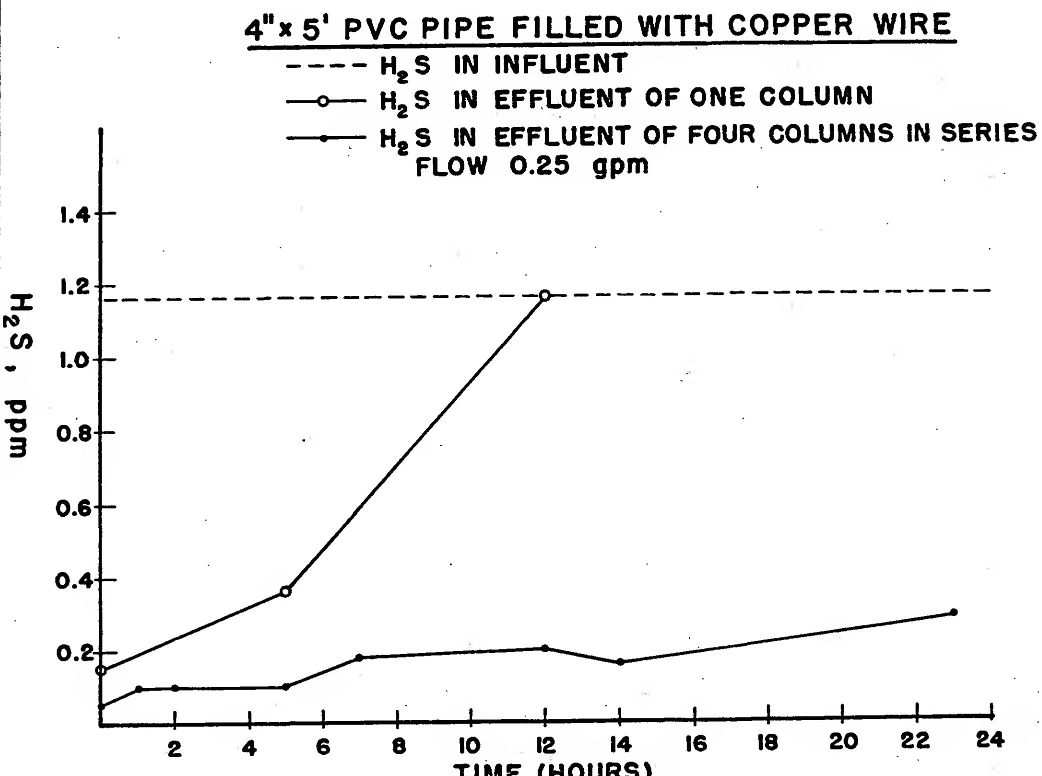

FIG. 8 - REMOVAL OF H_2S FROM WATER WITH COPPER WIRE

immediately preceding the carbon absorption unit where waters containing H_2S were to be sampled. The copper was cleaned once each day to insure maximum efficiency of the unit. It was assumed that the removal of organics by the copper was negligible since copper is an approved material for use in the installation of carbon absorption units.

Bacteriology. - Coliform determinations were made by Black Laboratories, Gainesville, Florida, using the membrane filter technique (MFT).

The Earle B. Phelps Sanitary Engineering Research Laboratory determined the 24-hour standard plate counts (SPC) at $35^{\circ}C$.

Iodine in the presence of chloramine. - In all studies requiring the determination of iodine (HIO) in the presence of chloramine, the colorimetric method developed by Black and Whittle[83] was used. When determinations were made in the laboratory, concentrations were precisely determined by using a Beckman* Model B Spectrophotometer. A Hach** iodine test kit Model ID-1 was used when determinations were made in the field.

Iodate. - In the absence of chloramine, iodates were determined colorimetrically, using the method developed by Black and Whittle.[83]

When chlorine, chloramine or iodine was present, iodates were determined by amperometric titration. All chlorine, chloramine and iodine were first titrated and then the pH was lowered to pH 2 and

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*Manufactured by Beckman Instruments, Inc., South Pasadena, Calif.

**Manufactured by Hach Chemical Co., Ames, Iowa.

excess potassium iodide added. After standing for three minutes the pH was raised to pH 4 and the iodine equivalent of iodate titrated with phenylarseneoxide.

Iodide. - Iodides in concentrations greater than 0.05 ppm were determined colorimetrically, using the procedure developed by Black and Whittle.[83] The determination of iodide in natural waters, however, required the use of a much more sensitive method. Samples were concentrated 10:1 and the iodide content determined by a procedure used for the determination of protein bound iodine as described by Sunderman.[84] The method is based upon evaluating the catalytic effect of the iodide ion on the rate of oxidation of the arsenite ion by ceric sulfate, under rigidly controlled conditions. All low-level iodide determinations were made by the Clinical Laboratories of Shands Teaching Hospital.

Radioactive iodine (^{131}I). - ^{131}I was determined on samples collected from well No. 2 at Lowell, using the whole body counting facilities of the Department of Radiology at the University of Florida Health Center. Facilities were such that a fairly large sample could be counted. For this reason a five-gallon sample contained in a glass bottle was used.

Counting equipment consisted of a four-inch by nine-inch NaI (TlI) crystal and a Packard* Model 116 multichannel analyzer. The analyzer was calibrated for 10 kev/channel. Frequent checks of the calibration were made by counting a ^{40}K source.

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*Manufactured by Packard Instrument Co., Inc., La Grange, Ill.

Count data showed that decay products of ^{226}Ra were present in the water. Correction of the count data for their presence was necessary since the energy spectrum for both ^{131}I and daughters of ^{226}Ra overlap in the 0.3 to 0.4 Mev range. Count data from a sample of water collected prior to the time ^{131}I was administered to test subjects was used to strip the spectrum of those components due to ^{226}Ra daughters.

A ^{131}I standard containing 0.425 µCi ^{131}I was prepared in the same type container as was used for the samples. The overall counting efficiency based on this standard was determined to be 0.77 percent. The ^{131}I content of both the standard and samples was based on the summation of counts in the corrected energy spectrum between 0.3 and 0.4 Mev.

V. POLLUTION OF THE FLORIDAN AQUIFER

Introduction

As previously stated, polluted water is known to be entering the ground at two locations on the periphery of the city. Further, it is known that polluted water is entering some of the wells in the city's well field.

This so-called baseline study has been designed to determine the extent to which the Floridan Aquifer is polluted in the Gainesville area. It is also designed to provide other information on water quality which will be useful in selecting the site for the development of a new well field in an area where the water is relatively free from pollution and of good chemical quality.

Discussion of Results

Forms of nitrogen. - Figures 9 through 12 and Tables 24 through 27 show the concentrations of nitrate, free ammonia, organic ammonia and nitrite, all expressed as nitrogen, in water from each sampling point. Except for two sampling points a decrease in the concentration of nitrates was observed over the sampling period. Values for both free and organic ammonia-N fluctuated during the period with perhaps a general trend upward during January and February. A measurable concentration of nitrite was found only twice, once at Alachua Sink and once at Orman Annis' well. High values for the three most prevalent forms of nitrogen were found in water from Lake Alice, Alachua Sink and well No. 3.

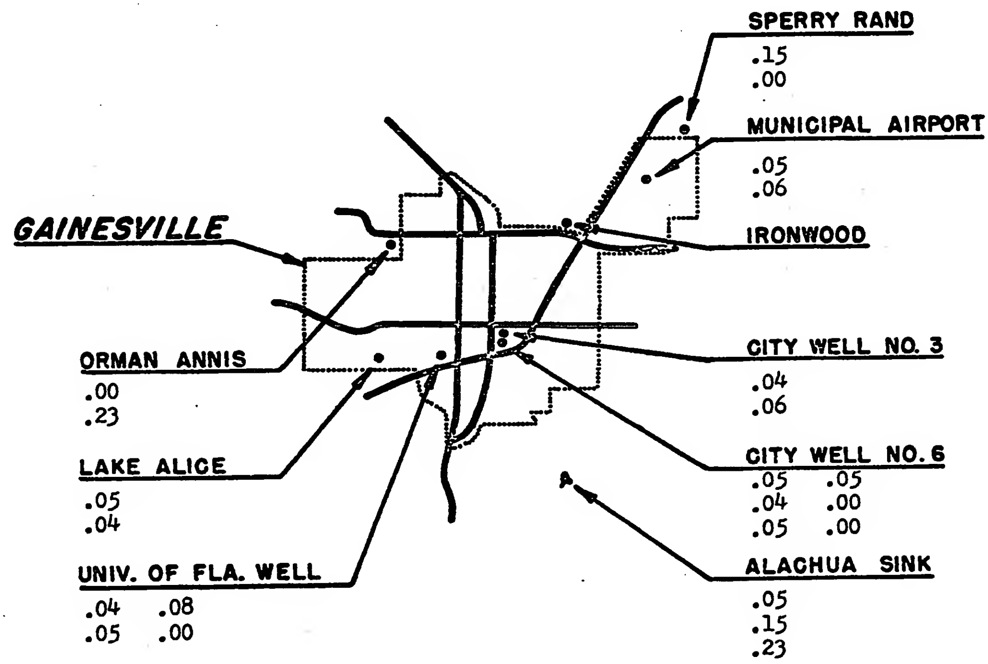

Fig. 9 - Nitrate-N Content of Water Within the Gainesville Area (ppm as N)

Table 24

Nitrate-N Content of Water Within the Gainesville Area (ppm as N)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6
City well No. 3	0.04		0.06					
City well No. 6	0.05	0.04	0.05	0.05	0.00			0.00
Univ. of Fla. well	0.04	0.05	0.08			0.00		
Lake Alice	0.05					0.04		
Alachua Sink		0.05	0.15				0.23	
Orman Annis				0.00			0.23	
Municipal Airport				0.05		0.06		
Sperry Rand Corp.				0.15				0.00

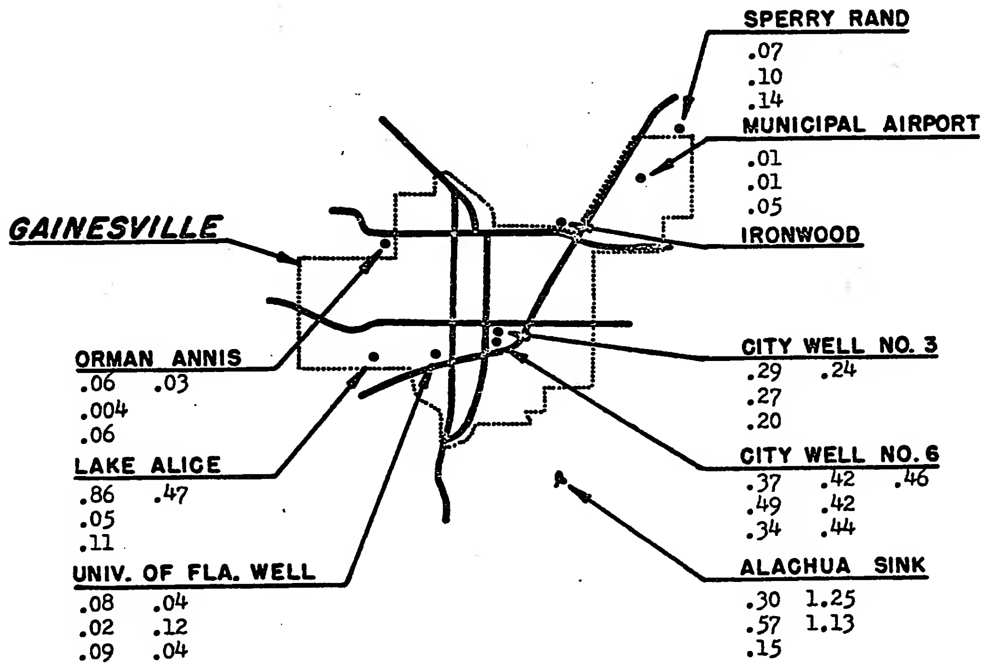

Fig. 10 - Free Ammonia-N in Water Within the Gainesville Area (ppm as N)

Table 25

Free Ammonia-N in Water Within the Gainesville Area
(ppm as N)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	0.29		0.27							0.20	0.24
City well No. 6	0.37	0.49	0.34	0.42	0.42			0.44			0.46
Univ. of Fla. well	0.08	0.02	0.09			0.04			0.12		0.04
Lake Alice	0.86					0.05			0.11		0.47
Alachua Sink		0.30	0.57				0.15			1.25	1.13
Orman Annis				0.06			0.004			0.06	0.03
Municipal Airport				0.01		0.01			0.05		
Sperry Rand Corp.				0.07				0.10			0.14

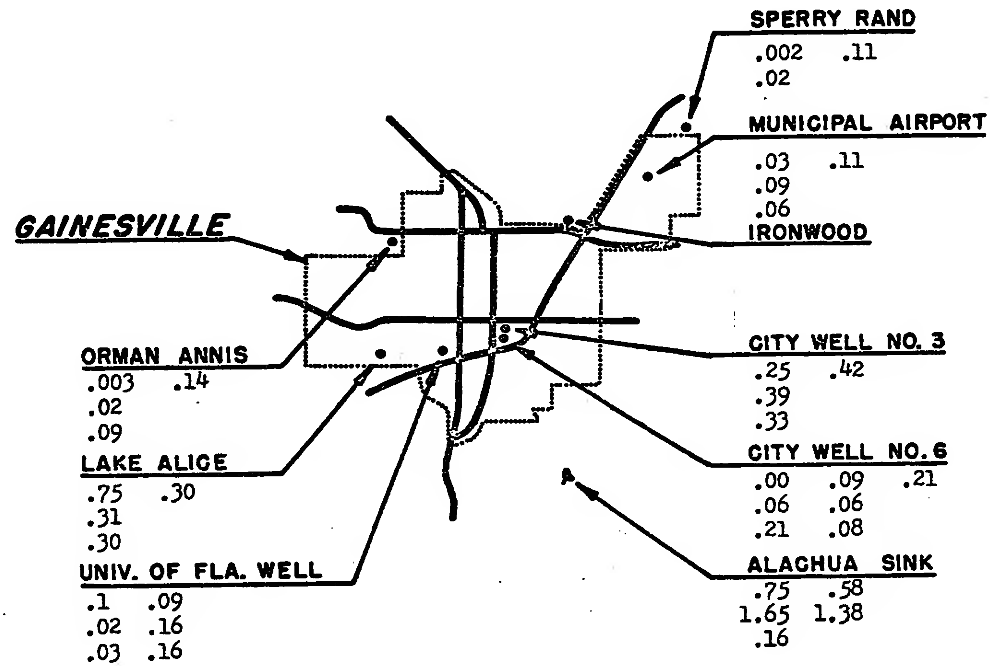

Fig. 11 - Organic Ammonia-N in Water Within the Gainesville Area (ppm as N)

Table 26

Organic Ammonia-N in Water Within the Gainesville Area
(ppm as N)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	0.25		0.39							0.33	0.42
City well No. 6	0.00	0.06	0.21	0.09	0.06			0.08			0.21
Univ. of Fla. well	0.10	0.02	0.03			0.09			0.16		0.16
Lake Alice	0.75					0.31			0.30		0.30
Alachua Sink		0.75	1.65				0.16			0.58	1.38
Orman Annis				0.003			0.02			0.09	0.14
Municipal Airport				0.03		0.09			0.06		0.11
Sperry Rand Corp.				0.002				0.02			0.11

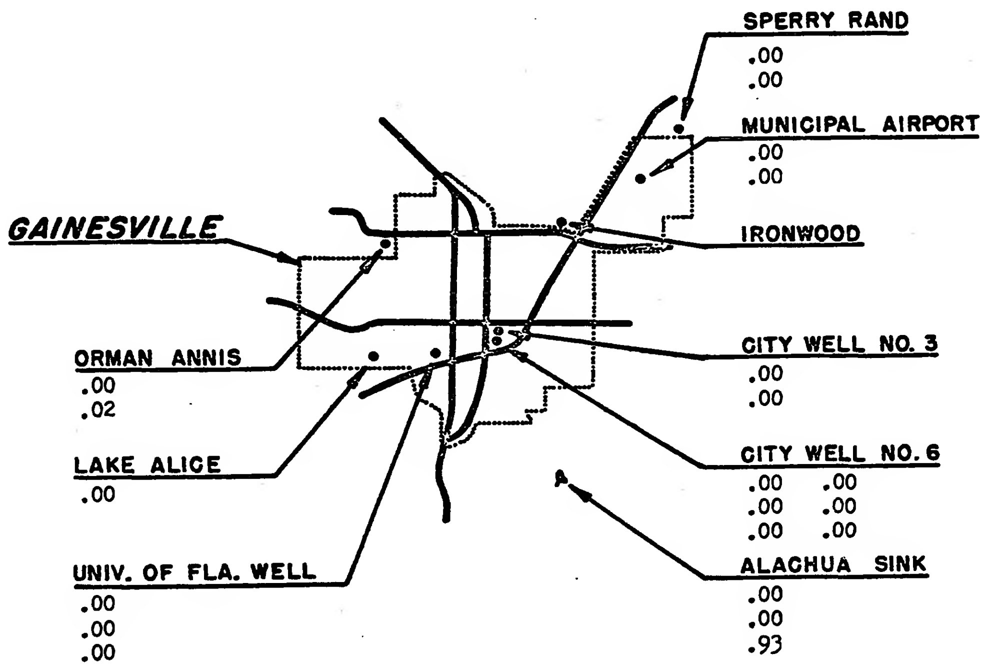

Fig. 12 - Nitrite-N Content of Water Within the Gainesville Area (ppm as N)

Table 27

Nitrite-N Content of Water Within the Gainesville Area (ppm as N)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6
City well No. 3	0.00		0.00					
City well No. 6	0.00	0.00	0.00	0.00	0.00			0.00
Univ. of Fla. well	0.00	0.00	0.00			Trace*		
Lake Alice	0.00					Trace*		
Alachua Sink		0.00	0.00				0.93	
Orman Annis				0.00			0.02	
Municipal Airport				0.00		0.00		
Sperry Rand Corp.				0.00				0.00

*Present but concentration less than 0.01 ppm

The presence of organic ammonia, free ammonia and nitrate-N in the concentrations found indicate that nitrogenous organic matter and its products of decomposition are present in waters to the west and south of the present well field. The absence of nitrite-N and the presence of nitrate-N suggest that the process of decomposition is stabilized and that the pollutants are not of recent origin.

Two hypotheses seem to have merit in explaining the relatively high free ammonia-N content of water from well No. 6: (1) pollution of very recent origin by sewage, or (2) the biological or chemical reduction of nitrates. Coliform organisms which are occasionally found in the water add strength to the first hypothesis, while the low concentrations of nitrate-N, absence of nitrite-N and the presence of hydrogen sulfide add strength to the latter hypothesis.

Low values for all forms of nitrogen were found in waters from sample points northeast of the city. This was to be expected since the piezometric level of water in this area is higher than that found in other areas of Gainesville.

COD. - Data which are presented in Figure 13 and Table 28 show that the highest COD values were obtained for Lake Alice, Alachua Sink and well No. 3. Intermediate to low values were obtained for well No. 6 and the University of Florida well, with still lower values obtained for sample points northeast of the city.

The COD of 20.6 ppm for the Orman Annis well is believed to be due either to a sampling or analytical error since such a high COD is highly unlikely without gross pollution. The low COD of 5.0 ppm for Alachua

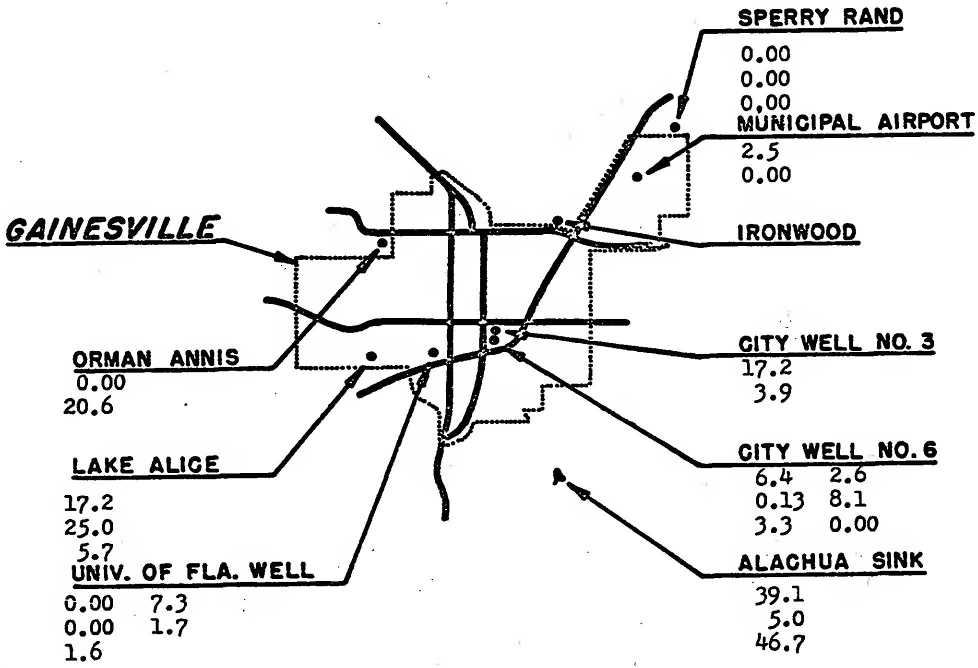

Fig. 13 - COD of Water Within the Gainesville Area (ppm)

Table 28

COD of Water Within the Gainesville Area (ppm)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12
City well No. 3	17.2		3.9						
City well No. 6	6.4	.13	3.3	2.6	8.1			0.00	
Univ. of Fla. well	0.00	0.00	1.6			7.3			1.7
Lake Alice	17.2					25.0			5.7
Alachua Sink		39.1	5.0				46.7		
Orman Annis				0.00			20.6		
Municipal Airport				2.5		0.00			
Sperry Rand Corp.				0.00				0.00	0.00

Sink occurred at the same time a low of 3.9 ppm was obtained for well No. 3.

These data, and those previously given, suggest that organic pollutants are present in ground water both south and west of the present well field. They further suggest that water northeast of the city is relatively free of organic pollutants.

Phosphate and chloride. - Both total phosphate and orthophosphate determinations were made on all samples collected during the first two months of this study. The results showed that orthophosphate was equal to total phosphate, indicating that no polyphosphates were present.

As may be seen from Table 29, the concentration of phosphates tended to increase during the sampling period except for the two sample points northeast of the city. Again, high concentrations were found in Lake Alice, Alachua Sink, and well No. 3, with lower values at well No. 6, University of Florida well and Orman Annis' well (Figure 14).

Figure 15 and Table 30 show that chlorides remained relatively constant during the sampling period. Higher values were obtained for Lake Alice and Alachua Sink, with intermediate values for the University of Florida well, wells No. 3 and No. 6 and the Orman Annis well.

The higher value for phosphates at the Orman Annis well on February 8 is believed to be an error since other analyses to not confirm the presence of pollutants in the water on that date.

It is interesting to note that well No. 6 and the University of Florida well show similar values for phosphates, chloride and nitrate as shown in Figures 11, 14, 15 and Tables 26, 29 and 30.

Table 29

Total Phosphate in Water Within the Gainesville Area
(ppm as PO_4)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	.75		.76							1.07	1.55
City well No. 6	.14	.17	.15	.16	.19			.24			0.25
Univ. of Fla. well	.18	.12	.20			.25			.24		0.30
Lake Alice	2.9					2.4			1.5		3.1
Alachua Sink		2.7	2.9				3.3			4.2	4.5
Orman Annis				.12			.15			0.18	1.25
Municipal Airport				.02		$<$ .01			.02		$<$ .01
Sperry Rand Corp.				.02				$<$ .01			0.03

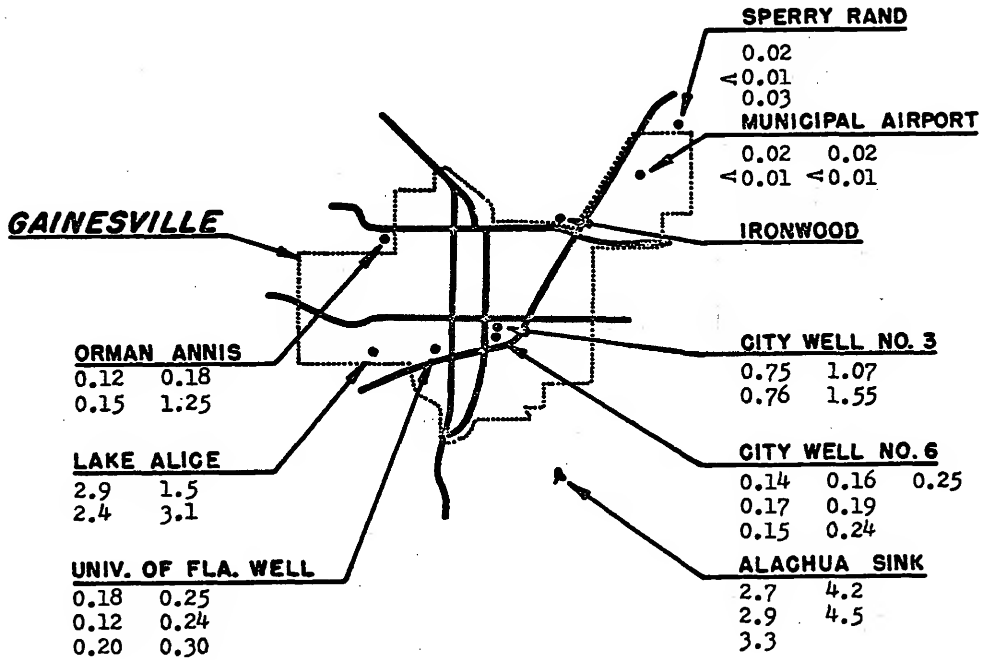

Fig. 14 - Total Phosphate in Water Within the Gainesville Area (ppm as PO_4)

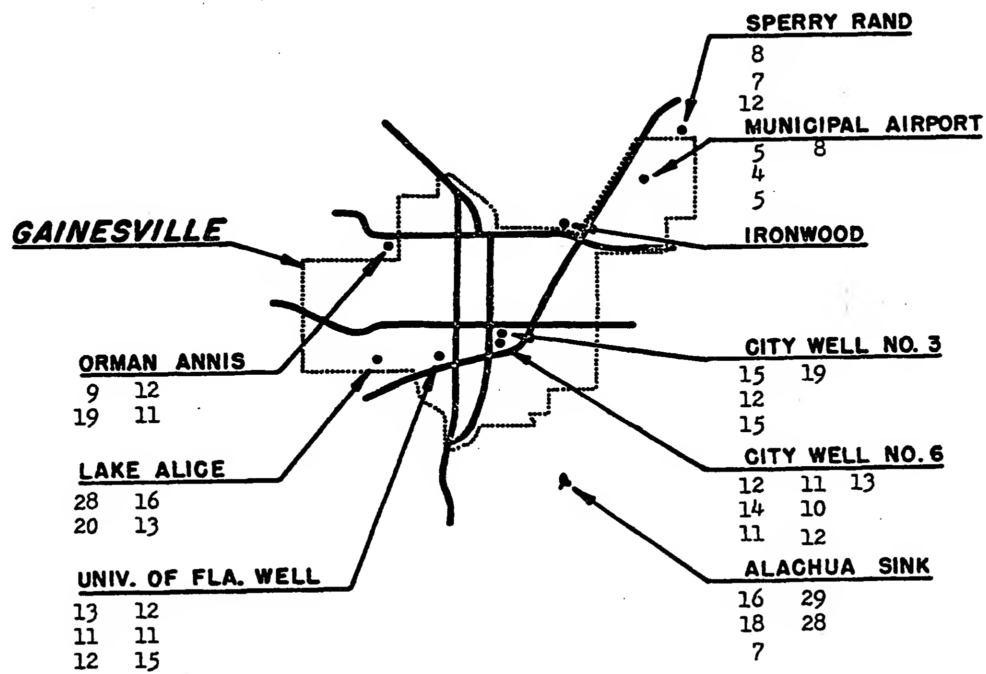

Fig. 15 - Chloride in Water Within the Gainesville Area (ppm)

Table 30

Chloride in Water Within the Gainesville Area (ppm)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	15		12							15	19
City well No. 6	12	14	11	11	10			12			13
Univ. of Fla. well	13	11	12			12			11		15
Lake Alice	28					20			16		13
Alachua Sink		16	18				7			29	28
Orman Annis				9			19			12	11
Municipal Airport				5		4			5		8
Sperry Rand Corp.				8				7			12

<u>ABS-LAS</u>. - The results obtained from the first few samples showed that the ABS-LAS content of the waters was near the lower limit of detection and its determination on the remaining samples was omitted. Apparently the biodegradability of the new detergents has virtually eliminated ABS-LAS pollutants in this area.

<u>Halogen demands</u>. - The chlorine demand of waters remained quite uniform during the sampling period except for Alachua Sink and Lake Alice where substantial decreases were noted. Data which are presented in Figure 16 and Table 31 show that the higher demands were found in water from Lake Alice, Alachua Sink and well No. 3 with a lower demand in well No. 6. Minimum values of from two to four ppm were obtained at all other points.

Data from Figure 17 and Table 32 show that except for values obtained at Lake Alice, the iodine demand of the waters increased during the sampling period. Of particular interest is the three-fold increase for well No. 3, the four-fold increase for well No. 6, and the increased values at Alachua Sink. As shown in Figure 17, higher values were obtained for Alachua Sink, Lake Alice and wells No. 3 and No. 6. All other values ranged from two to six ppm.

The increase in iodine demand without a corresponding increase in chlorine demand is difficult to understand. Chlorine being chemically more active than iodine would be expected to show the greater increase. In evaluating these data it is well to remember that even though the iodine demand of the water at times was equal to or greater than the chlorine demand on a ppm basis, the actual "kinetic" demand of iodine on

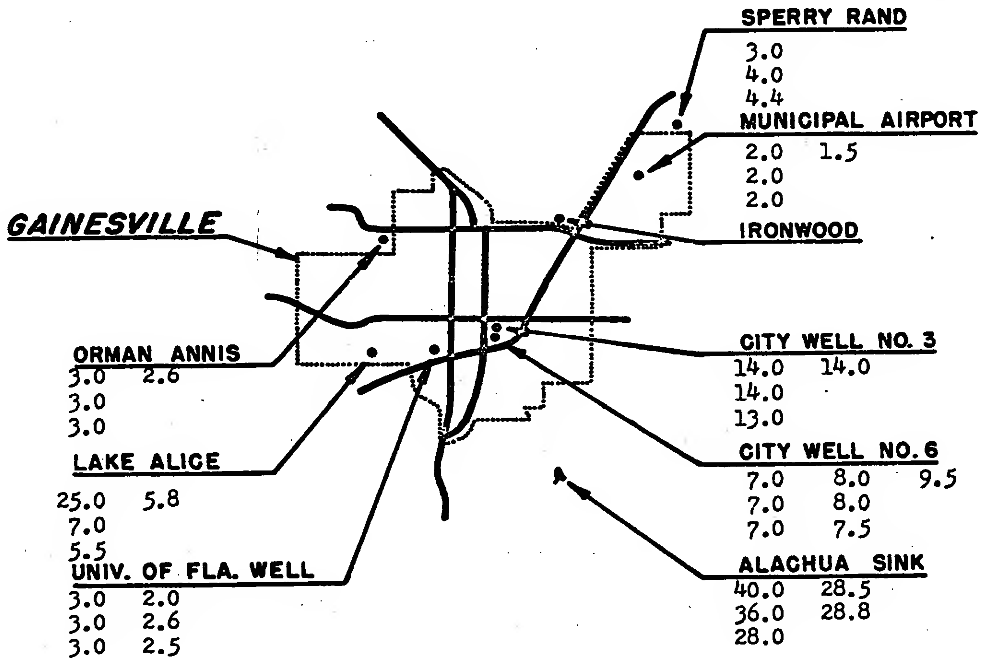

Fig. 16 - Chlorine Demand of Water Within the Gainesville Area (ppm)

Table 31

Chlorine Demand of Water in the Gainesville Area (ppm)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	14.0		14.0							13.0	14.0
City well No. 6	7.0	7.0	7.0	8.0	8.0			7.5			9.5
Univ. of Fla. well	3.0	3.0	3.0			2.0			2.6		2.5
Lake Alice	25.0					7.0			5.5		5.8
Alachua Sink		40.0	36.0				28.0			28.5	28.8
Orman Annis				3.0			3.0			3.0	2.6
Municipal Airport				2.0		2.0			2.0		1.5
Sperry Rand Corp.				3.0				4.0			4.4

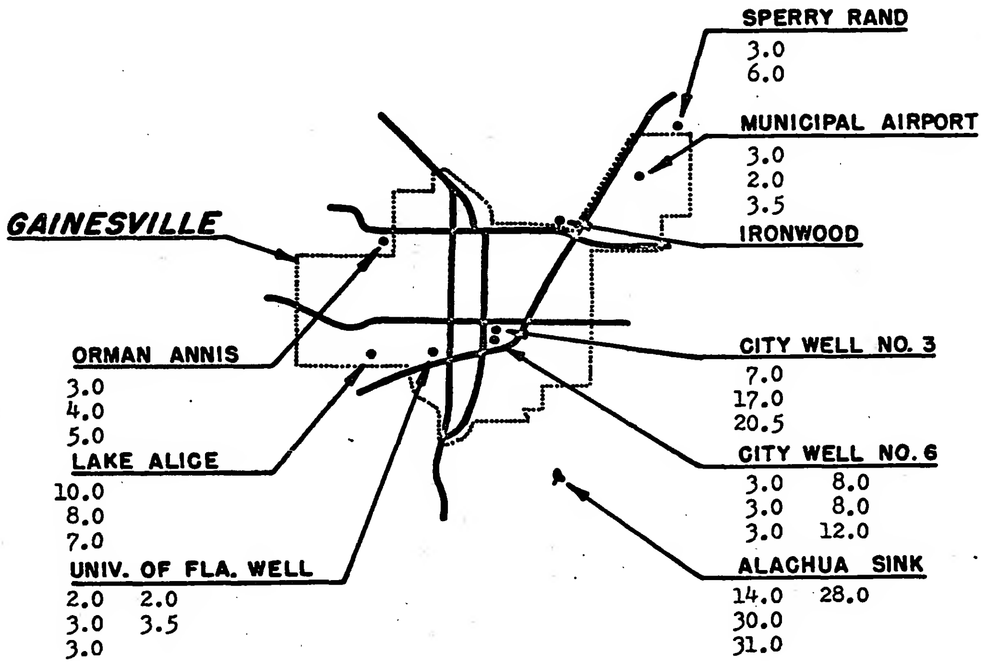

Fig. 17 - Iodine Demand of Water Within the Gainesville Area (ppm)

Table 32

Iodine Demand of Water in the Gainesville Area (ppm)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18
City well No. 3	7.0		17.0							20.5
City well No. 6	3.0	3.0	3.0	8.0	8.0			12.0		
Univ. of Fla. well	2.0	3.0	3.0			2.0			3.5	
Lake Alice	10.0					8.0			7.0	
Alachua Sink		14.0	30.0				31.0			28.0
Orman Annis				3.0			4.0			5.0
Municipal Airport				3.0		2.0			3.5	
Sperry Rand Corp.				3.0				6.0		

a molar basis was only one-third that of chlorine due to the difference in molecular weights of the two elements.

The data from both chlorine and iodine demands suggest that higher concentrations of organic matter are present in ground water to the west and south of the present well field than in other areas around the city. The low values obtained for sample points northeast of the city indicate that organics are present in low concentrations in this area.

CCE and CAE. - The small amount of hydrogen sulfide which passed through the collumns packed with copper was apparently readily adsorbed by the activated carbon, and either during the drying or extraction procedure was converted to elemental sulfur. The presence of sulfur would, to the extent of its presence, give high CCE values. No sulfur was present in the CAE.

CCE values were obtained at four sample points with no sulfur visible in the extracted organics. While sulfur was visible in samples obtained from all other points, some samples had a negligible quantity present and were used for comparison purposes.

The data shown in Table 33 indicate that values in excess of the 200 ppb limit as recommended by the 1962 Drinking Water Standards[64] were exceeded only for Alachua Sink and well No. 3, although it is believed that some values obtained for well No. 6 would approach 200 ppb if sulfur were not present.

Values for CAE (Table 34) were determined to be substantially higher than those for CCE. Alachua Sink and well No. 3 show the highest values. The presence of pollution from either natural sources or highly

Table 33

Carbon Chloroform Extractables in Water Within the Gainesville Area (ppb)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12	Jan. 18
City well No. 3	160^{+}		237^{+}							194^{+}
City well No. 6	328^{++}	89^{+}	558^{++}	35^{+}	61^{+}			696^{++}		
Univ. of Fla. well	43^{-}	43^{-}	28^{-}			48^{-}			535^{++}	
Lake Alice	180^{-}					127^{-}			103^{-}	
Alachua Sink		503^{-}	806^{-}				400^{-}			767^{-}
Orman Annis				36^{-}			66^{+}			52^{+}
Municipal Airport				35^{+}		9^{-}				
Sperry Rand Corp.				341^{++}				44^{+}	31^{+}	

$^{-}$No sulfur visible in the residue

$^{+}$Sulfur visible in the residue

$^{++}$Much sulfur visible in the residue

Table 34

Carbon Alcohol Extractables in Water Within the Gainesville Area (ppb)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12	Jan. 18
City well No. 3										1810
City well No. 6								1690		
Univ. of Fla. well	202					577			1056	
Lake Alice	410					504			650	
Alachua Sink							1810			2075
Orman Annis				1139			340			1022
Municipal Airport						328			697	
Sperry Rand Corp.								523		

oxidized sewage is suggested by these data.

Bacteriology. - The data presented in Figure 18 and Tables 35 and 36 show that a large number of organisms, presumably of fecal origin, are present in water from Lake Alice and Alachua Sink. The number of coliform organisms is low in water from the University of Florida well and well No. 6. In view of the fact that an increase in standard plate count coincides with the presence of coliform organisms in these two wells, the changes are believed to be real rather than due to sampling error.

The large number of each organism which is present in water from Lake Alice and Alachua Sink strongly suggests that pollutants of fecal origin are present in each and that these polluted waters are finding their way into wells on the University of Florida campus and into the city's well field.

Color. - While the presence of color in a water is not necessarily an indication of sewage pollution, it could serve as an excellent tracer for determining the route which water takes in traveling from one location to another.

Figure 19 and Table 37 show the intensity of color found at each of the sample points. Note that the color of the water at Lake Alice is less than that in well No. 3, while water from Alachua Sink is significantly higher in organic color than well No. 3.

These data suggest that Alachua Sink is the prime source of the organic color which is found in the city wells penetrating the upper permeable stratum of the Floridan Aquifer (Tables 18 and 37).

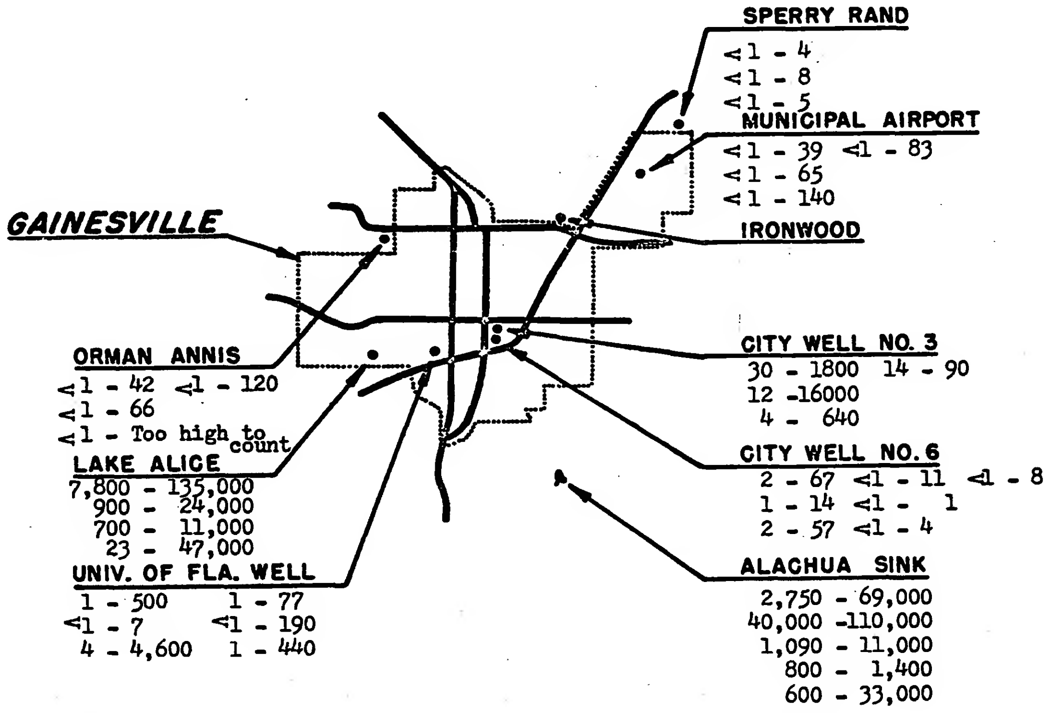

Fig. 18 - Coliform and Standard Plate Count for Water Within the Gainesville Area

Table 35

Coliforms in Water Within the Gainesville Area
(coliforms per 100 ml)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	30		12							4	14
City well No. 6	2	1	2	< 1	< 1			< 1			< 1
Univ. of Fla. well	1	< 1	4			1			< 1		1
Lake Alice	7,800					900			700		23
Alachua Sink		2,750	40,000				1,090			800	600
Orman Annis				< 1			< 1			< 1	< 1
Municipal Airport				< 1		< 1			< 1		< 1
Sperry Rand Corp.				< 1				< 1			< 1

Table 36

Standard Plate Count for Water Within the Gainesville Area
(colonies per ml)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	1800		16,000							640	90
City well No. 6	67	14	57	11	<1			4			8
Univ. of Fla. well	500	7	4,600			77			190		440
Lake Alice	135,000					24,000			11,000		47,000
Alachua Sink		69,000	110,000				11,000			1,400	33,000
Orman Annis				42			66			high*	120
Municipal Airport				39		65			140		83
Sperry Rand Corp.				4				8			5

*Too high to count

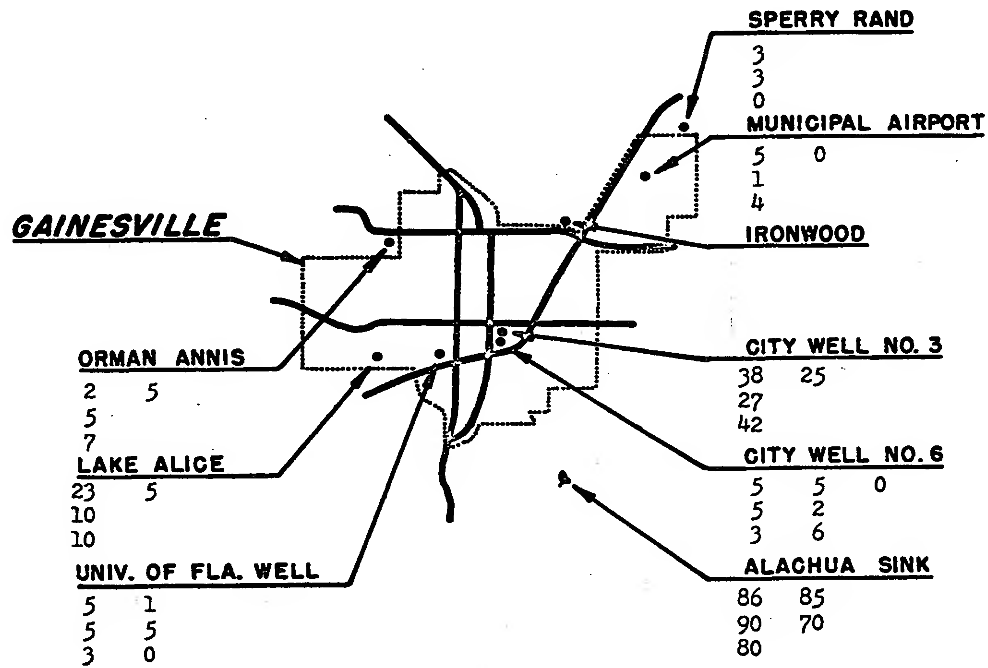

Fig. 19 - Color of Water Within the Gainesville Area (units)

Table 37

Color of Water in the Gainesville Area (units)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	38		27							42	25
City well No. 6	5	5	3	5	2			6			0
Univ. of Fla. well	5	5	3			1			5		0
Lake Alice	23					10			10		5
Alachua Sink		86	90				80			85	70
Orman Annis				2			5			7	5
Municipal Airport				5		1			4		0
Sperry Rand Corp.				3				3			0

No doubt, the water entering Alachua Sink is diluted with other water in the aquifer as it travels from the sink to well No. 3. It is quite possible that water from Lake Alice is mixing with water from the sink to yield a water having a reduced intensity of color at well No. 3.

Iodide. - The relatively high iodide concentration in water from Lake Alice probably results from the iodination of the University of Florida swimming pool for the past three years. In this study it has been used as a unique tracer to show the extent to which ground water in the area is receiving water from the two drainage wells at Lake Alice.

Data which are given in Table 38 and Figure 20 show that the iodide content of water from Lake Alice, the University of Florida well, wells No. 3 and No. 6, and the Orman Annis well is higher than that found in other wells in the area. The increase in iodide levels which was observed on March 22 is probably the result of the iodination of the city's water supply for a 12-hour period on February 23.

These data suggest that water from Lake Alice is appearing in the University of Florida well, Orman Annis well, well No. 3 and well No. 6. Data which are tabulated in Table 39 further substantiate that high iodides are found in all of the wells in the city's well field.

Samples of water were collected from wells in the Ocala area to get some indication of the normal level of iodide in water from the upper, intermediate, and lower strata of the Florida Aquifer. The important chemical and physical characteristics of these three sources of water in the Ocala area are shown in Tables 40 and 41. A comparison of the chemical characteristics of water from different depths in the

Table 38

Iodide Content of Water in the Gainesville Area (ppb)

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8	Mar.22
City well No.3	8.3		7.4							8.2	11.4	--
City well No.6	11.6	11.9	11.4	10.9				13.1			14.3	15.5
Univ. of Fla. well	6.8	11.1	8.9			9.7			10.4		9.8	14.5
Lake Alice	20.2					18.1			17.8		24.3	18.7
Alachua Sink		6.9	5.6				4.9			7.0	7.0	11.1
Orman Annis				6.4			6.5			7.2	9.1	10.3
Municipal Airport				2.8		2.1			4.9		3.4	3.4
Sperry Rand Corp.				6.4							8.6	11.5

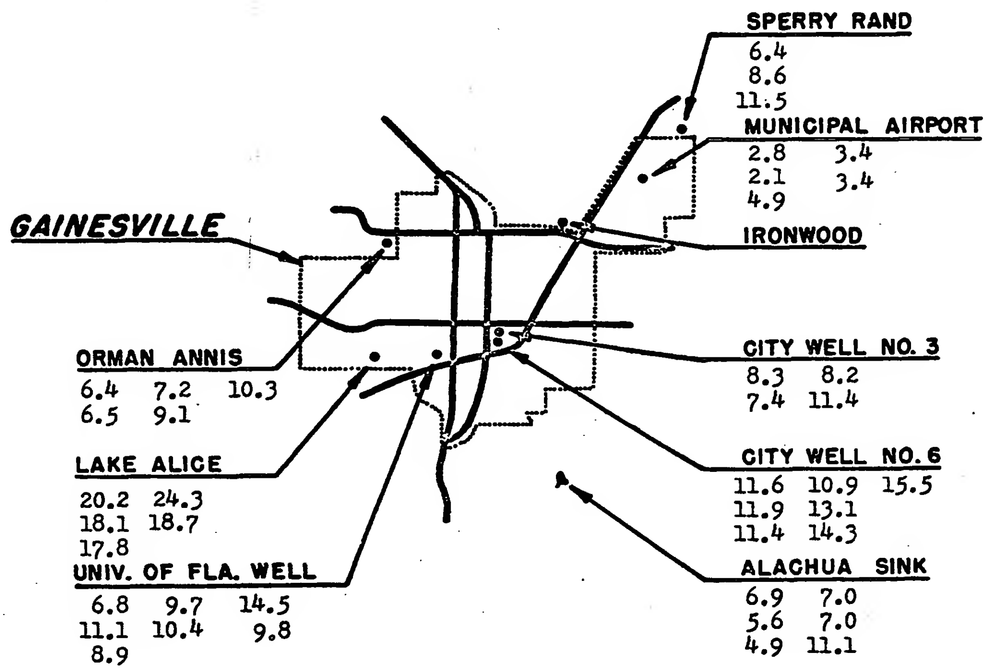

Fig. 20 - Iodide Content of Water Within the Gainesville Area (ppb)

Ocala area and the Gainesville area may be obtained by comparing the data shown in Tables 17 and 18 with thosein Tables 40 and 41. These data show that water from well No. 6 and the City of Ocala well No. 3 has similar chemical characteristics. Geological considerations and well logs also indicate that water from these two wells is probably derived from the same stratum of the aquifer.[65]

Table 39

Iodide Content of Water from Wells in the City's Well Field
March 22, 1967

Well Number	Iodide, ppb
2	9.5
3	11.4*
4	12.0
5	7.0
6	15.5
7	12.4

*This value for Feb. 8, 1967.

Table 40

Characteristics of Three Sources of Water in the Ocala Area

	Silver Springs	City of Ocala well No. 3	Libby McNeil and Libby well No. 3
Total depth (ft)	shallow	440	1083
Casing diameter (in)	---	20	26
Depth of casing (ft)	---	259	850
Pump yield (mgd)	---	4.0	7.5

The iodide content of water from the City of Ocala well No. 3 is only about 50 percent of that found in well No. 6. This single series of determinations only admits the possibility that water from Lake Alice may be passing the barrier provided by the dense stratum of limestone and dolomite which separates the upper and lower permeable strata of the aquifer. Many determinations of iodide content over a considerable period of time will be required before the data may be considered as significant.

A possible route for water to enter the lower stratum through deep wells on the University of Florida campus was suggested earlier in this study. A diagram illustrating this possible route may be seen in Figure 21.

Table 41

Chemical Characteristics of Water from the Ocala Area

	Silver Springs (Shallow zone)	City of Ocala well No. 3 (Deeper zone)	Libby McNeil and Libby well No. 3 (Deeper zone)
Total dissolved solids	208	350	553
Total hardness, as $CaCO_3$	209	289	483
Carbonate hardness, as $CaCO_3$	167	150	222
Noncarbonate hardness, as $CaCO_3$	50	136	263
Alkalinity, as $CaCO_3$	167	150	222
Calcium, as $CaCO_3$	176	242	420
Magnesium, as $CaCO_3$	33	56	63
Chlorides, as Cl	10.3	12.1	17.6
Iodides, as I	9.0	7.6	16.9
Sulfates, as SO_4	25	100	208
Organic color	2	3	2
pH	7.7	7.63	7.4

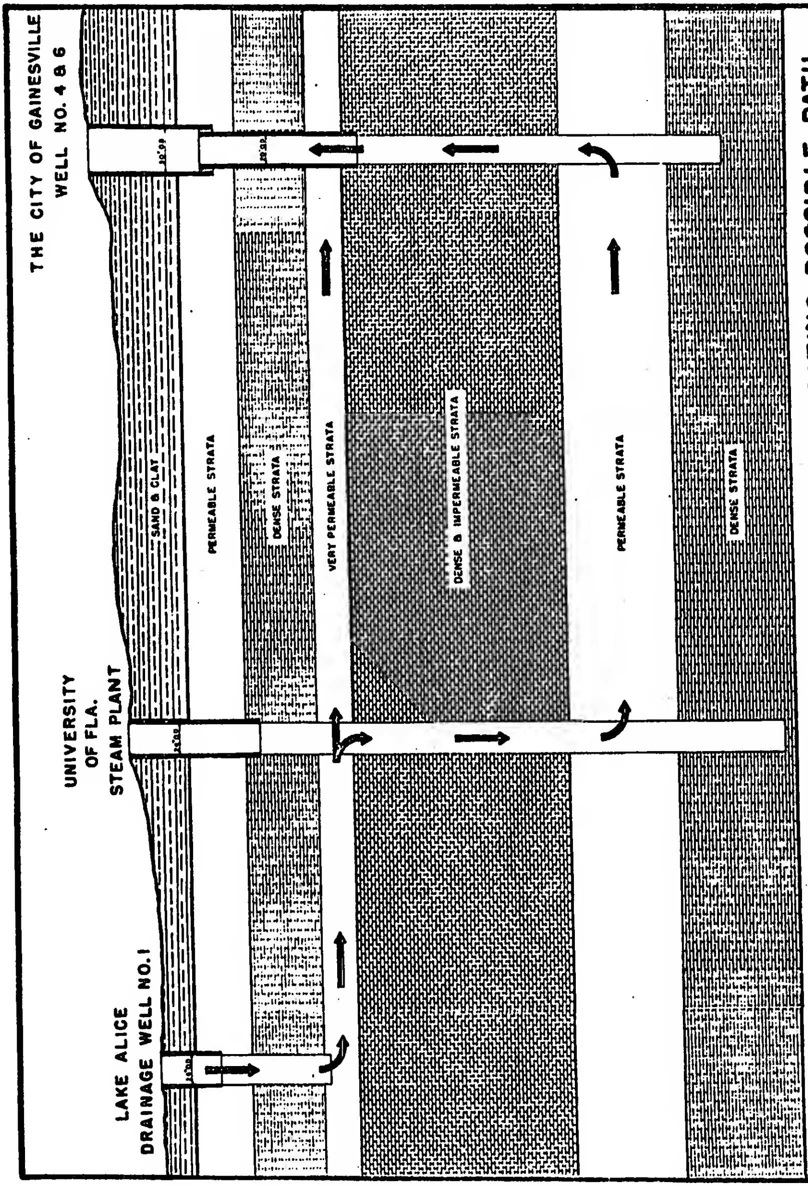

Fig. 21 - DIAGRAMMATIC WEST TO EAST CROSS-SECTION INDICATING POSSIBLE PATH OF POLLUTION

<u>Alkalinity, total hardness, H_2S, and pH</u>. - Collectively, the data presented in Figures 22 through 24 and Tables 42 through 45 are typical for surface and well waters in the area. The high values for both alkalinity and total hardness obtained for Lake Alice are a result of the large volume of well water discharged into the lake after being used for cooling in the university steam plant.

All well waters are of low to moderate hardness (130 to 330 ppm as $CaCO_3$) with noncarbonate hardness ranging from 15 to 140 ppm. The relatively low total hardness and noncarbonate hardness found in water northeast of the city suggests that this is a desirable area in which to develop a new well field.

These data show no evidence of pollutants from either domestic or industrial sources.

<u>Rainfall</u>. - Total rainfall for the period Nov. 1, 1966 to Feb. 28, 1967 was 11.68 inches or 0.65 inches above the 60-year normal of 11.03 inches.[85,86] A plot of the daily precipitation is given in Figure 25. The distribution of rainfall received was such that slow recharge of the aquifer occurred without any pronounced peaks which might have a flushing effect. As a result, no direct correlation between rainfall and ground water quality could be found.

<u>Corollary Studies at Lowell, Florida</u>

A part of the continuing studies at three state correctional institutions at Lowell, Florida, includes the evaluation of thyroid function by determining the radioactive iodine (RAI) uptake on a representative group of inmates who have been drinking iodinated water exclusively for more than three years. The ^{131}I which is used for RAI uptake

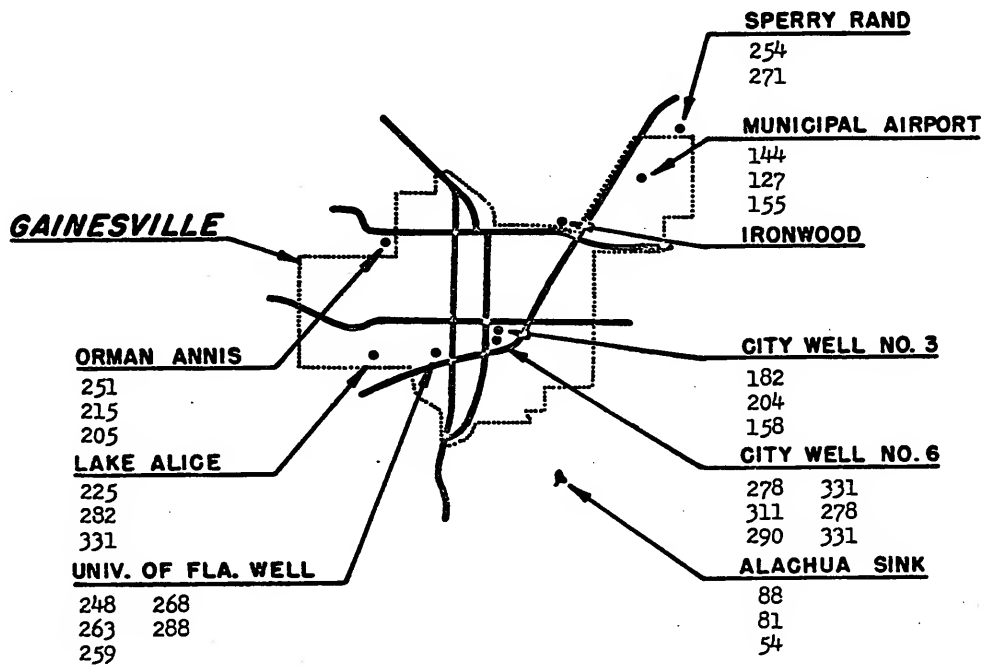

Fig. 22 - Total Hardness of Water Within the Gainesville Area (ppm as $CaCO_3$)

Table 42

Total Hardness of Water in the Gainesville Area
(ppm as $CaCO_3$)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12	Jan. 18
City well No. 3	182		204							158
City well No. 6	278	311	290	331	278			331		
Univ. of Fla. well	248	268	263			259			288	
Lake Alice	225					282			331	
Alachua Sink		88	81				54			
Orman Annis				251			215			205
Municipal Airport				144		127			155	
Sperry Rand Corp.				254				271		

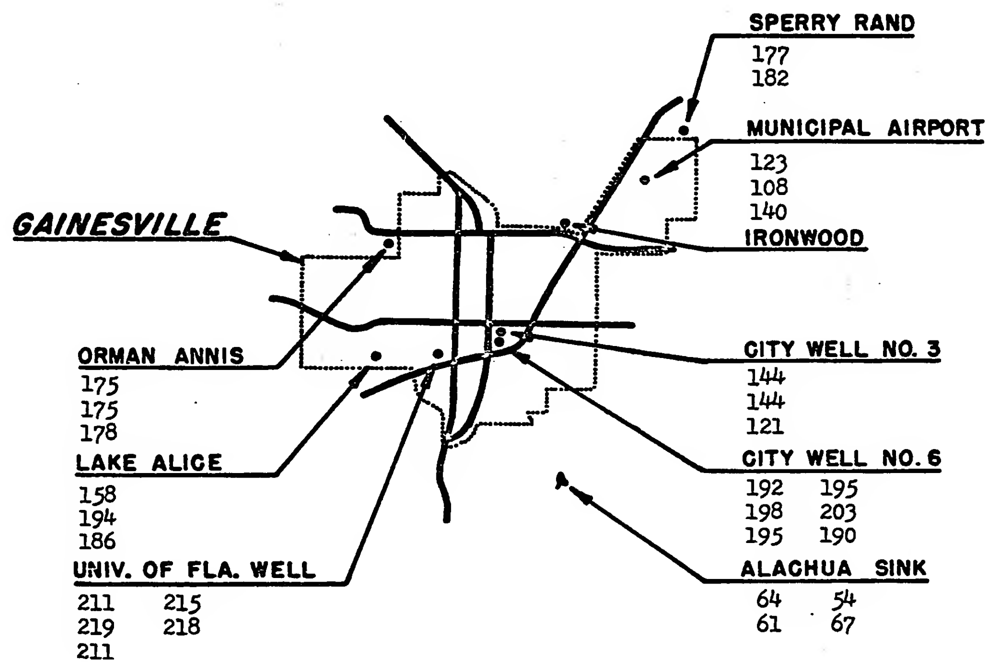

Fig. 23 - Total Alkalinity of Water Within the Gainesville Area (ppm as $CaCO_3$, P alkalinity = 0)

Table 43

Total Alkalinity* of Water in the Gainesville Area
(ppm as $CaCO_3$)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12	Jan. 18
City well No. 3	144		144							121
City well No. 6	192	198	195	195	203			190		
Univ. of Fla. well	211	219	211			215			218	
Lake Alice	158					194			186	
Alachua Sink		64	61				54			67
Orman Annis				175			175			178
Municipal Airport				123		108			140	
Sperry Rand Corp.				177				182		

*Phenothaline alkalinity was zero for all samples

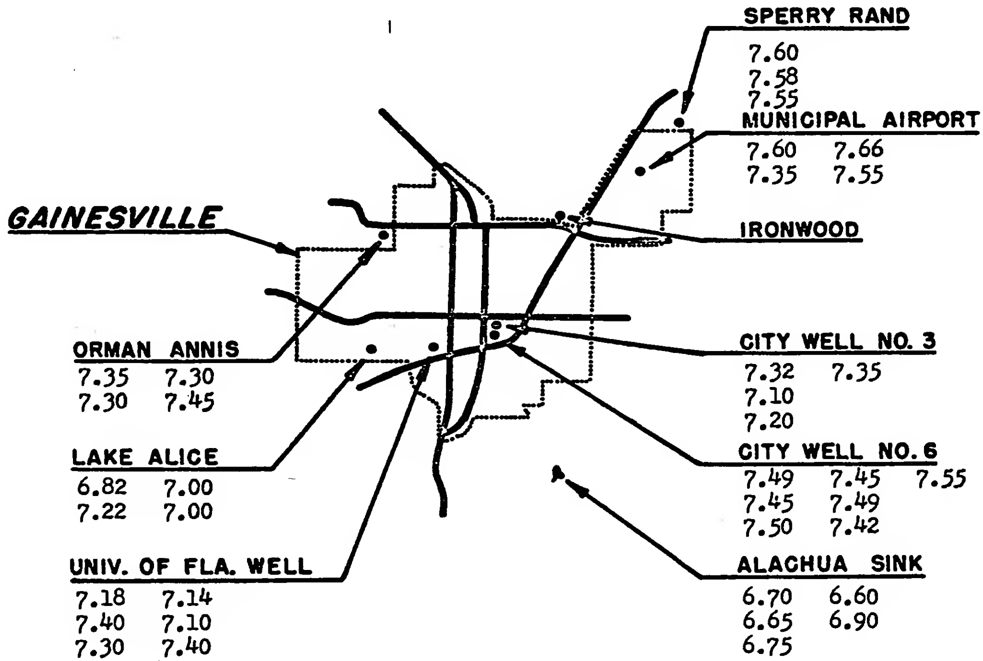

Fig. 24 - The pH of Water Within the Gainesville Area (units)

Table 44

The pH of Water in the Gainesville Area

	Nov.2	Nov.11	Nov.21	Nov.26	Dec.3	Dec.10	Dec.17	Jan.6	Jan.12	Jan.18	Feb.8
City well No. 3	7.32		7.10							7.20	7.35
City well No. 6	7.49	7.45	7.50	7.45	7.49			7.42			7.55
Univ. of Fla. well	7.18	7.40	7.30			7.14			7.10		7.40
Lake Alice	6.82					7.22			7.00		7.00
Alachua Sink		6.70	6.65				6.75			6.60	6.90
Orman Annis				7.35			7.30			7.30	7.45
Municipal Airport				7.60		7.35			7.66		7.55
Sperry Rand Corp.				7.60				7.58			7.55

Table 45

Hydrogen Sulfide in Water in the Gainesville Area (ppm)

	Nov. 2	Nov. 11	Nov. 21	Nov. 26	Dec. 3	Dec. 10	Dec. 17	Jan. 6	Jan. 12	Jan. 18
City well No. 3	0.92		0.88							0.64
City well No. 6	0.84	1.13	1.26	1.16	1.17			1.20		
Univ. of Fla. well	0.08	0.00	0.16			0.00			0.00	
Lake Alice	0.00					0.00			0.00	
Alachua Sink		0.00	0.00				0.00			0.00
Orman Annis				0.08			0.36			0.00
Municipal Airport				0.24		0.04			0.00	
Sperry Rand Corp.				0.92				0.87		

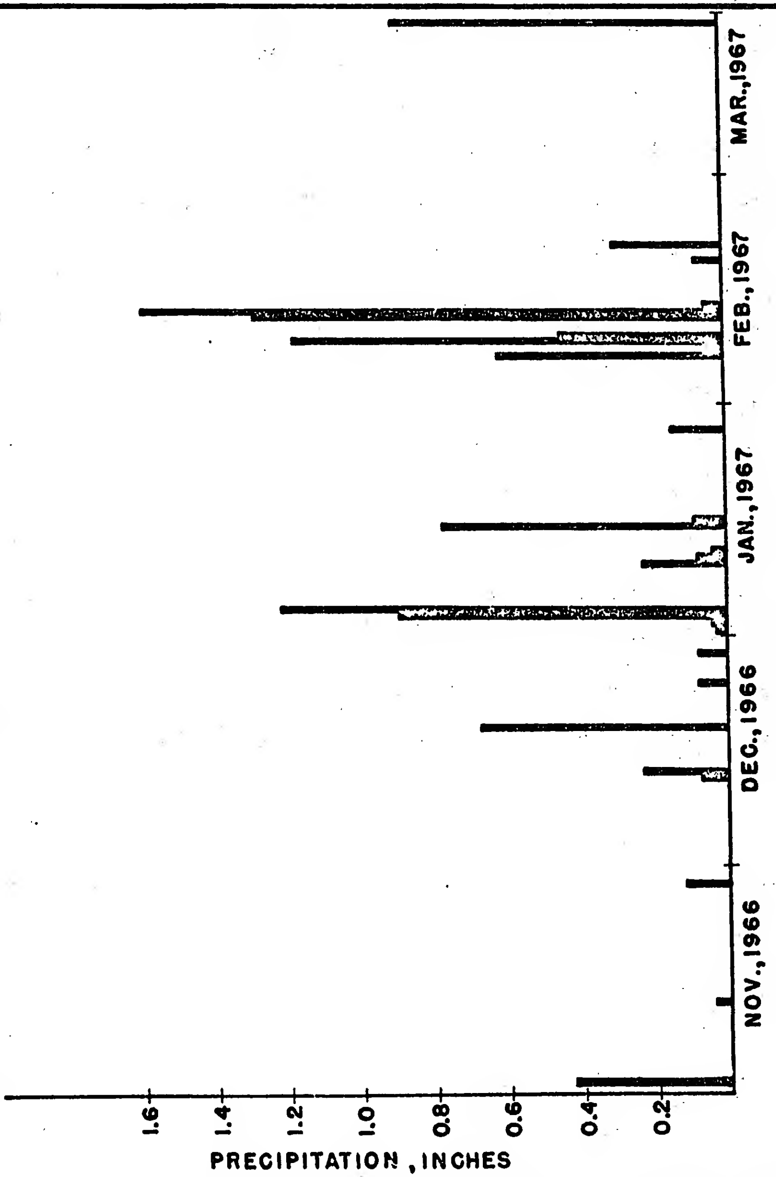

FIG. 25 – RAINFALL DURING THE PERIOD OF INVESTIGATION

determinations is excreted from the body rapidly, thus providing a natural tracer for the evaluation of a sewage pollution problem which was believed to be present in the area.[67]

Effluent from the sewage treatment facility at the Florida Correctional Institution for Women is discharged into a drainage ditch located approximately 1,000 feet from two wells which serve as the source of water for the institution.

Coliform organisms are present in more than 50 percent of 100 ml samples from well No. 2 and in about 30 percent of those from well No. 1.

Twice during December, 1966, ^{131}I was administered to test subjects for RAI uptake evaluation. On each occasion samples of sewage effluent and water from well No. 2 were collected on a continuous basis and their ^{131}I content determined. As expected, the samples of sewage effluent contained ^{131}I during these periods. Data presented in Figure 26 and Table 46 show that the level of ^{131}I in the well water sharply increased between three and four days after each test when ^{131}I was administered to test subjects.

The maximum concentration of ^{131}I in the well water was well below the MPC (3×10^{-6} µCi/ml) set by the Florida State Board of Health.[87]

This study shows that the effluent from the sewage treatment plant at the Florida Correctional Institution for Women is at least one source of sewage pollution in water obtained from well No. 2. It is also another typical example of what can and does take place when untreated or treated sewage enters the porous, very cavernous and highly permeable aquifer which is characteristic of limestone areas.

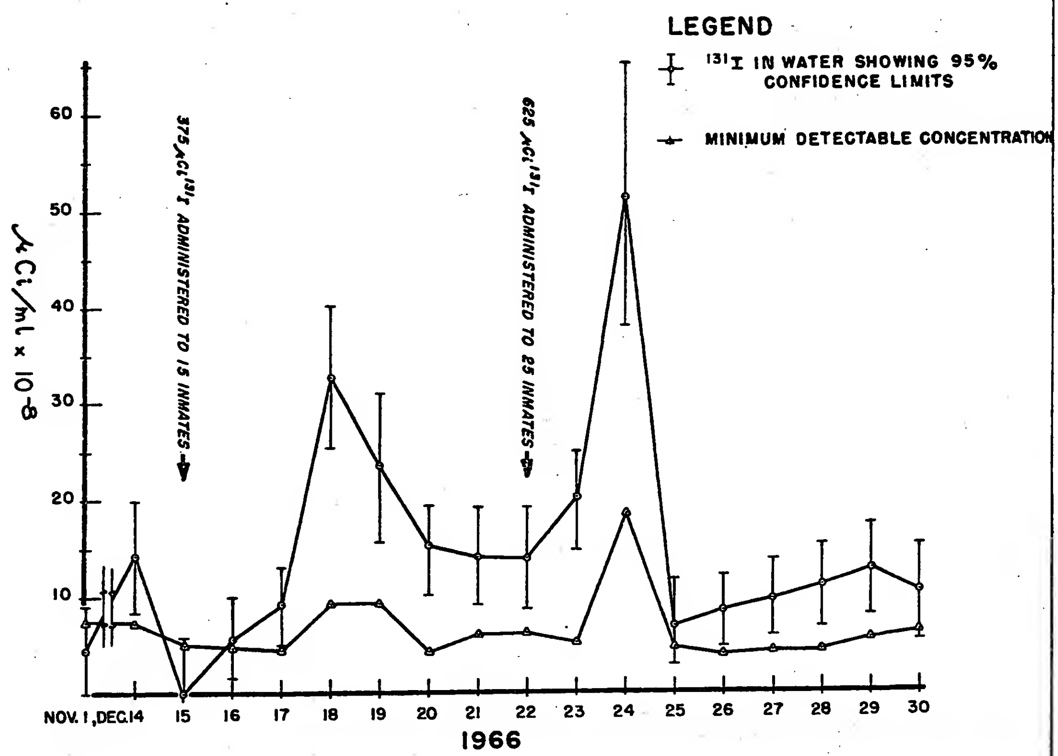

FIG.26- ^{131}I IN WATER FROM WELL NO. 2 (GIRLS' SCHOOL, LOWELL, FLA.)

Table 46

^{131}I Content of Well Water from Well No. 2, Girls' School, Lowell, Florida

Date (1966)	Net Count (cpm)	^{131}I $\mu Ci/ml \times 10^{-8}$	95 Percent Confidence Limits $\mu Ci/ml \times 10^{-8}$	Minimum Detectable $\mu Ci/ml \times 10^{-8}$
Nov. 1	14.8	4.56	4.49	5.05
Dec. 14	46.6	14.3	5.82	7.20
Dec. 15	0.0	0.0	5.72	7.20
Dec. 16	18.7	5.79	4.25	4.65
Dec. 17	29.8	9.17	4.10	4.37
Dec. 18	107.0	32.7	7.27	9.33
Dec. 19	76.6	23.6	7.20	9.33
Dec. 20	49.9	15.4	4.03	4.22
Dec. 21	45.9	14.1	5.14	6.20
Dec. 22	45.3	14.0	5.27	6.25
Dec. 23	66.0	20.3	4.56	5.11
Dec. 24	167.0	51.4	13.2	18.7
Dec. 25	22.5	6.90	4.12	4.56
Dec. 26	27.4	8.45	3.82	3.94
Dec. 27	31.6	9.73	3.94	4.05
Dec. 28	35.9	11.1	4.31	4.13
Dec. 29	41.5	12.8	4.80	5.51
Dec. 30	33.9	10.4	5.14	6.10

Summary

Pollutants of sewage origin are shown to be present in Lake Alice, Alachua Sink, University of Florida well, and wells No. 3 and No. 6. Both Alachua Sink and the drainage wells at Lake Alice are believed to be the primary openings through which effluent from both the city and campus sewage treatment plants enter the Floridan Aquifer. The data indicate that water from both of these sources is probably present in the upper stratum of the aquifer. The data further indicate that only water from Lake Alice is entering the lower stratum. A possible route for pollutants to enter the lower stratum is shown to exist on the University of Florida campus.

Wells located northeast of the city are shown to yield water of excellent chemical and bacteriological quality. All data indicate that by relocating the city's well field in this area, water of good quality can be obtained.

No direct correlation between rainfall and ground water quality could be shown; however, the concentration of some pollutants increased during the test period which was a normally dry period of the year.

VI. THE GAINESVILLE WATER SYSTEM

Introduction

In laying groundwork preparatory to iodinating the water supply, the answers to many questions were sought. These questions included:

1. Can a residual be maintained to the end of the distribution system?
2. Will the buildup of iodate be appreciable?
3. What will be the effect of the various types of pipe coating, scale, tuberculation and organic matter on the iodine residual as well as the buildup of iodate?
4. What method should be used for adding iodine to the system?

While laboratory studies are necessary in avoiding many problems which could arise in applying new techniques directly to a system, the final test must necessarily be a system trial. No laboratory test can exactly duplicate conditions which exist in the system.

Both laboratory studies and a system trial were initiated to answer the aforementioned questions. The results of both are included in the remaining pages of this section.

Change in the Bacteriological Quality of Water from the Well to the Consumer

In order to evaluate the effectiveness of water treatment during a period of chlorination,a study was made to determine the change in bacteriological quality of the water as it passed through the water treatment plant and distribution system.

On four occasions samples of the water were taken at preselected points in the treatment plant for pH, chlorine residual and bacteriological determinations. On each occasion water was being pumped from wells No. 5 and No. 7 at a combined rate of 10 mgd with 10.5 ppm of chlorine added to the Accelator. The location of each sample point is given in Table 47.

For bacteriological determinations, samples one through six were collected in sterile bottles containing sodium thiosulfate. Sample seven was collected in sterile bottles containing no sodium thiosulfate so that the effect, if any, of additional contact time with chlorine could be observed. All samples for bacteriological determinations were taken in triplicate.

Table 47

Location of Sample Points in the Water Treatment Plant

Sample Number	Location
1	Influent from wells
2	Accelator effluent
3	In flume immediately upstream of the recarbonation basin
4	In flume entering the rapid sand filters after recarbonation
5	Filter effluent
6	Tap in laboratory at water treatment plant
7	Effluent from sand filters collected in bottles which contained no sodium thiosulfate

From Tables 48 through 51, note that no coliform organisms were found in water leaving the Accelator. Here the pH is maintained between pH 10.2 and 10.3 with a free chlorine residual between 1.7 and 2 ppm and a contact time of approximately one hour.

Standard plate counts were reduced to between 10 and 20 in water leaving the Accelator, even though counts in the raw water ranged between 180 and 970. Further decreases in the standard plate count were observed as water passed through the remainder of the plant.

Chlorine residuals determined by amperometric titration show that a free chlorine residual was maintained through the plant. While ammonium sulfate is added to the water between the Accelator and the recarbonation basin (between sample points 2 and 3) a few minutes are required to complete the reaction between free chlorine and the ammonium ion added.

In evaluating these data on the basis of chlorine residual, it must be remembered that even though a free chlorine residual exists, less than 10 percent of it exists as hypochlorous acid and greater than 90 percent as the hypochlorite ion due to the high pH of the water. In all but one instance (Table 50) chloramines accounted for at least one-half of the total chlorine present in the water leaving the Accelator. Both chloramines and the hypochlorite ion are known to be relatively ineffective as disinfectants.[11]

Data published by Riehl, Weiser and Rheims[88] and others show that E. coli and other bacteria are killed by exposure to water of high pH for a period of time which depends on the pH of the water. A pH value

Table 48

Changes in Bacteriological Quality, pH and Chlorine Residual as Water Passes Through the Water Treatment Plant, 3 to 5 AM, Nov. 29, 1966

Sample No.	Coliform			SPC*	pH	Amperometric			Contact Time (min) (calculated)	Sample Time (AM)
	Membrane Filter*	MPN 35°C	MPN 44.5°C			Free Cl_2	Comb. Cl_2	Total Cl_2		
1	18	7.0	2.0	837	7.20	0	0	0	0	4:10
2	< 1	< 2.0	< 2.0	13	10.2	1.71	1.85	3.56	57.5	3:42
3	< 1	< 2.2	< 2.2	10	10.2	0.73	2.79	3.52	58.3	4:20
4	< 1	< 2.2	< 2.2	8	8.75	0.70	2.44	3.14	60.1	4:30
5	< 1	< 2.2	< 2.2	7	8.70	0.18	2.62	2.80	64.1	4:50
6	< 1	< 2.2	< 2.2	4	8.90	0.01	2.06	2.07	--	5:10

*Average of three values

Table 49

Changes in Bacteriological Quality, pH and Chlorine Residual as Water Passes Through the Water Treatment Plant, 5 to 6 AM, Nov. 29, 1966

Sample No.	Coliform: Membrane Filter*	Coliform: MPN 35°C	Coliform: MPN 44.5°C	SPC*	pH	Amperometric: Free Cl_2	Amperometric: Comb. Cl_2	Amperometric: Total Cl_2	Contact Time (min) (calculated)	Sample Time (AM)
1	68	7.0	< 2.0	970	7.25	0	0	0	0	5:30
2	< 1	< 2.0	< 2.0	9	10.30	2.02	2.10	4.12	57.5	5:35
3	< 1	< 2.2	< 2.2	7	10.20	0.90	2.99	3.89	58.3	5:42
4	< 1	< 2.2	< 2.2	8	8.40	0.80	2.86	3.66	60.1	5:48
5	< 1	< 2.2	< 2.2	6	8.45	0.15	2.49	2.64	64.1	6:02
6	< 1	< 2.2	---	6	8.70	0.02	2.09	2.11	---	6:10
7	< 1	< 2.2	< 2.2	7	8.70	0.02	2.09	2.11	314	6:15

*Average of three values

Table 50

Changes in Bacteriological Quality, pH and Chlorine Residual as Water Passes Through the Water Treatment Plant, 3 to 4 AM, Dec. 20, 1966

Sample No.	Coliform			SPC*	pH	Amperometric			Contact Time (min) (calculated)	Sample Time (AM)
	Membrane Filter*	MPN								
		35°C	44.5°C			Free Cl_2	Comb. Cl_2	Total Cl_2		
1	9	2.0	--	410	7.39	0	0	0	0	3:12
2	< 1	< 2.0	< 2.0	13	10.12	2.08	1.51	3.59	57.5	3:22
3	< 1	< 2.2	< 2.2	14	10.26	1.71	2.44	4.15	58.3	3:35
4	< 1	< 2.2	< 2.2	12	7.80	1.30	1.00	2.30	60.1	3:53
5	< 1	< 2.2	< 2.2	9	7.81	0.88	0.57	1.45	64.1	4:00
6	< 1	< 2.2	< 2.2	4	8.47	0.28	1.36	1.64	---	4:12

*Average of three values

Table 51

Changes in Bacteriological Quality, pH and Chlorine Residual as Water Passes Through the Water Treatment Plant, 4 to 5 AM, Dec. 20, 1966

Sample No.	Coliform			SPC*	pH	Amperometric			Contact Time (min) (calculated)	Sample Time (AM)
	Membrane Filter*	MPN								
		35°C	44.5°C			Free Cl_2	Comb. Cl_2	Total Cl_2		
1	9	16	< 2.2	180	7.45	0	0	0	0	4:24
2	< 1	< 2.2	< 2.2	17	10.19	2.00	2.07	4.07	57.5	4:26
3	< 1	< 2.2	< 2.2	11	10.32	1.52	3.00	4.52	58.3	4:30
4	< 1	< 2.2	< 2.2	9	7.89	0.74	2.22	2.96	60.1	4:50
5	< 1	< 2.2	< 2.2	10	8.01	0.52	1.06	1.58	64.1	4:55
6	< 1	< 2.2	< 2.2	8	8.42	0.22	1.30	1.52	---	5:10
7	< 1	--	--	8	8.11	0.32	1.30	1.62	379.0	5:15

*Average of three values

of 11.0 or more is necessary, however, for disinfection within the retention time provided in most plants.

The bacteriological quality of water taken from four points in the distribution system was determined once each week from Nov. 8, 1966 through April 4, 1967. The location of each sample point is given in Table 52.

Table 52

Sampling Points in Distribution System for Bacteriological Analyses

Sample Point	Location
No. 1	County Jail, 6th St. at 10th Ave., S.E.
No. 2	Holiday Inn, 13th St. at 18th Place, S.E.
No. 3	Littlewood School, 34th St. at 8th Ave., N.W.
No. 4	PepsiCola Bottling Co., 1950 N.E. 27th Ave.

Data which will be presented later show the length of time required for water to travel from the water treatment plant to point No. 1 to be approximately three hours, points No. 2 and No. 3, 12 hours, and point No. 4, 27 hours.

Data which are presented in Table 53 show that no coliforms were found to be present at any sample point during the sample period. Except for two samples collected on Dec. 28, 1966, the standard plate counts were low. The two high plate counts are probably due to contamination; however, complaints of taste in the water at point No. 3 have

Table 53

Coliform and Standard Plate Count in the Distribution System During a Period of Chlorination

Sample Point	No. 1		No. 2		No. 3		No. 4	
Date	Coliform	SPC	Coliform	SPC	Coliform	SPC	Coliform	SPC
Nov. 8, 1966	<1	4	<1	5	<1	1	<1	3
Nov. 29, 1966	<1	2	<1	4	<1	4	<1	3
Dec. 13, 1966	<1	3	<1	4	<1	3	<1	2
Dec. 20, 1966	<1	2	<1	1	<1	1	<1	4
Dec. 28, 1966	<1	3	<1	8	<1	160	<1	>1000
Jan. 10, 1967	<1	3	<1	3	<1	4	<1	6
Jan. 17, 1967	<1	2	<1	3	<1	1	<1	1
Jan. 25, 1967	<1	3	<1	3	<1	3	<1	3
Feb. 7, 1967	<1	1	<1	4	<1	3	<1	<1
Feb. 14, 1967	<1	3	<1	11	<1	4	<1	2
Feb. 28, 1967	<1	1	<1	1	<1	1	<1	1
Mar. 7, 1967	<1	1	<1	1	<1	3	<1	2
Mar. 14, 1967	<1	2	<1	1	<1	1	-	-
Mar. 22, 1967	<1	1	<1	1	<1	2	<1	1
Mar. 28, 1967	<1	1	<1	1	<1	1	<1	1
Apr. 4, 1967	<1	3	<1	2	<1	2	<1	1

been received in the past and in addition, a sample collected from that point in February, 1967, showed a heavy algal growth when exposed to sunlight for several days. Similar observations were not obtained for point No. 4.

These data, together with those provided by the city's routine testing program, demonstrated that a water meeting the standards of bacterial quality as set by the 1962 Drinking Water Standards[64] is being produced from raw water of questionable purity. At the present time no standards have been set for viral quality.

Laboratory Studies

Halogen residuals in pipe. - Sections of pipe removed from both the old and new parts of the distribution system were used in the laboratory to determine (a) the persistence of HIO and NH_2Cl with time and (b) the rate of buildup of iodate. The data would be expected to reflect the effect, if any, of the various types of pipe coating, scale, tuberculation and organic matter on each of the vectors.

The pipe from the newer part of the system was an eight-inch cement-tar lined pipe with a uniform coating of calcium carbonate overlaying the pipe lining. No breaks or chips were noted in either the lining or calcium carbonate coating.

Pipe from the older part of the distribution system showed evidence of numerous tubercles. Streaks of ferric oxide were visible on top of the calcium carbonate coating as a result of ruptured tubercles.

A five-foot section was cut from a much larger section of each pipe. The pipe was set upright with one end in concrete. Each pipe was

flushed with tap water for three days to make certain that the pipe was thoroughly conditioned to tap water.

Data which are presented in Figure 27 show the persistence of HIO and chloramine in the presence of HIO in each of the pipes when the initial concentration of iodine as the iodide ion was 1.0 ppm.

Both the chloramine and HIO residuals dropped to almost zero within 36 hours in the older pipe. Residuals in the newer pipe were more persistent. However, the HIO residual dropped to zero in five days, with a substantial concentration of chloramine remaining.

Since the HIO residual in the newer pipe dropped very slowly after 48 hours and tangentially approached the abscissa at five days, it was felt that by slightly increasing the iodide ion concentration it might be possible to maintain a low HIO residual over a much longer period of time.

The results obtained from the addition of 1.1 ppm of iodine as iodide are shown in Figure 28. Note the increase in the persistence of the HIO residual in both pipes. It is of interest to note that in the newer pipe a detectable concentration of HIO remained after the chloramine residual dropped to zero.

After both the chloramine and HIO residuals were determined to be zero, the concentrations of both iodide and iodate were determined on each. The results are shown in Table 54.

Since a significant concentration of iodide ion was found to be present in each pipe, the decrease in chloramine residual appears to be the limiting factor in maintaining an HIO residual once a certain minimum

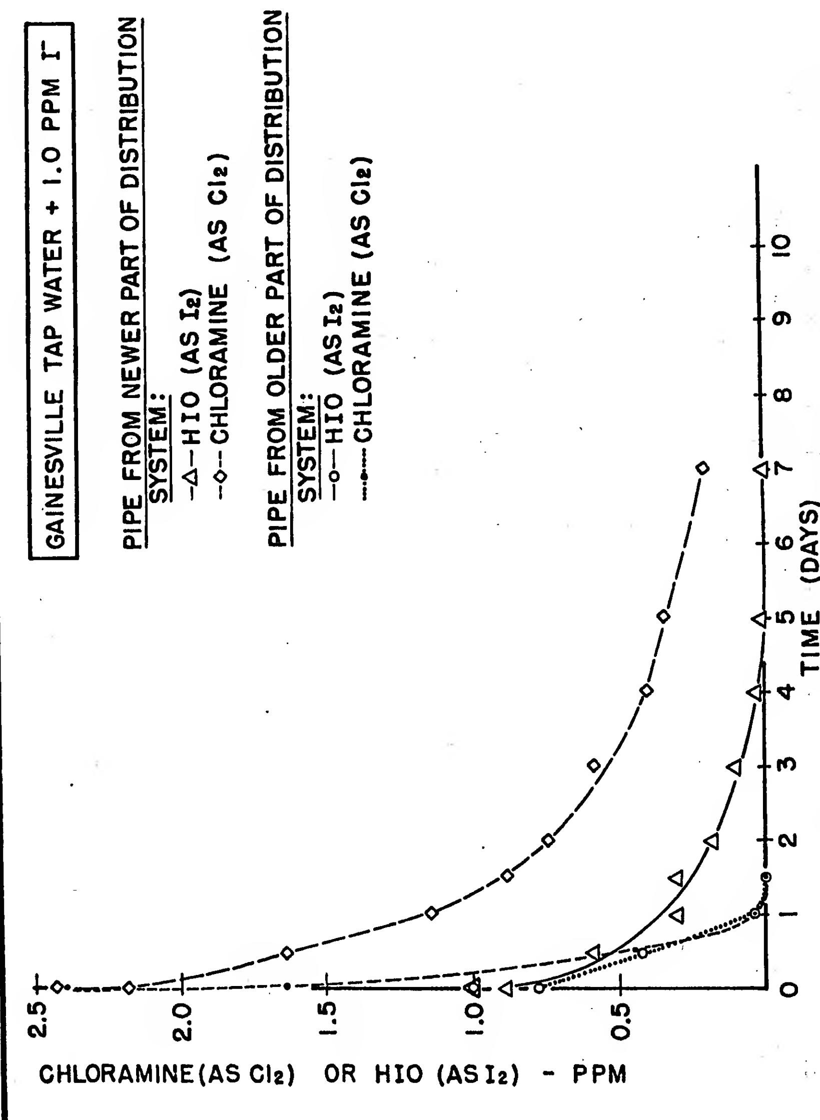

FIG.27- PERSISTENCE OF HIO AND CHLORAMINE IN THE REMOVED PIPE

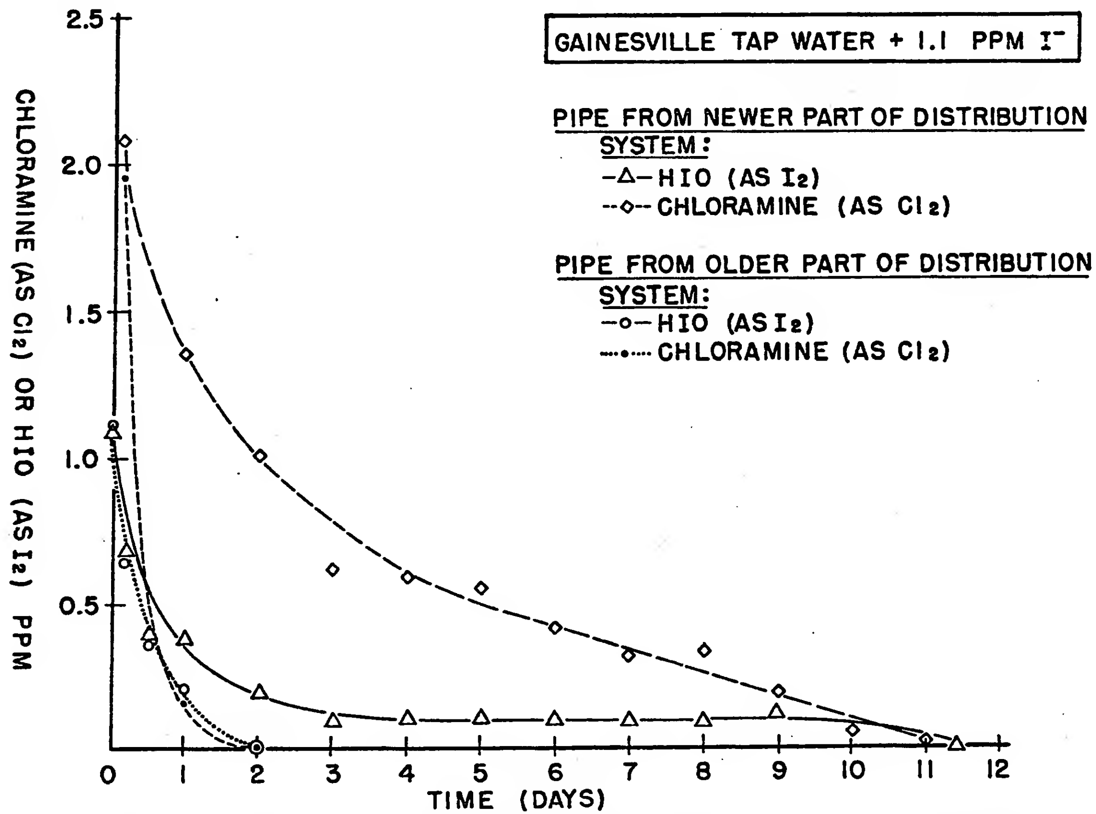

FIG.28 - PERSISTENCE OF HIO AND CHLORAMINE IN THE REMOVED PIPE

Table 54

Concentration of Iodide and Iodate in Iodinated Water

	Older Pipe	Newer Pipe
Iodate (ppm)	0.14	0.15
Iodide (ppm)	0.33	0.12
Initial iodide (ppm)	1.08	1.08
Unaccounted for (ppm)	0.61	0.81
pH	8.45	8.55

iodine demand has been satisfied.

Halogen residuals in glass containers. - A corollary experiment in which glass jars were used instead of pipe shows that both the HIO and chloramine residuals are more easily maintained in glass than in pipe (Figure 29).

Chloramine residuals in pipe and glass. - The persistence of chloramine residuals without added iodide ion when contained in the older pipe, newer pipe and glass is shown in Figure 30. These data show that the type of container or in this case the lining makes a tremendous difference in the persistence of chloramine. Even though the HIO and chloramine residual dropped rapidly in the older pipe (Figures 27 and 28) there was less chloramine available to oxidize the iodide ion due to a rapid decrease in chloramine residual alone.

Rates of reaction. - The persistence of chloramine alone and chloramine in the presence of HIO for each of two pipes as well as glass

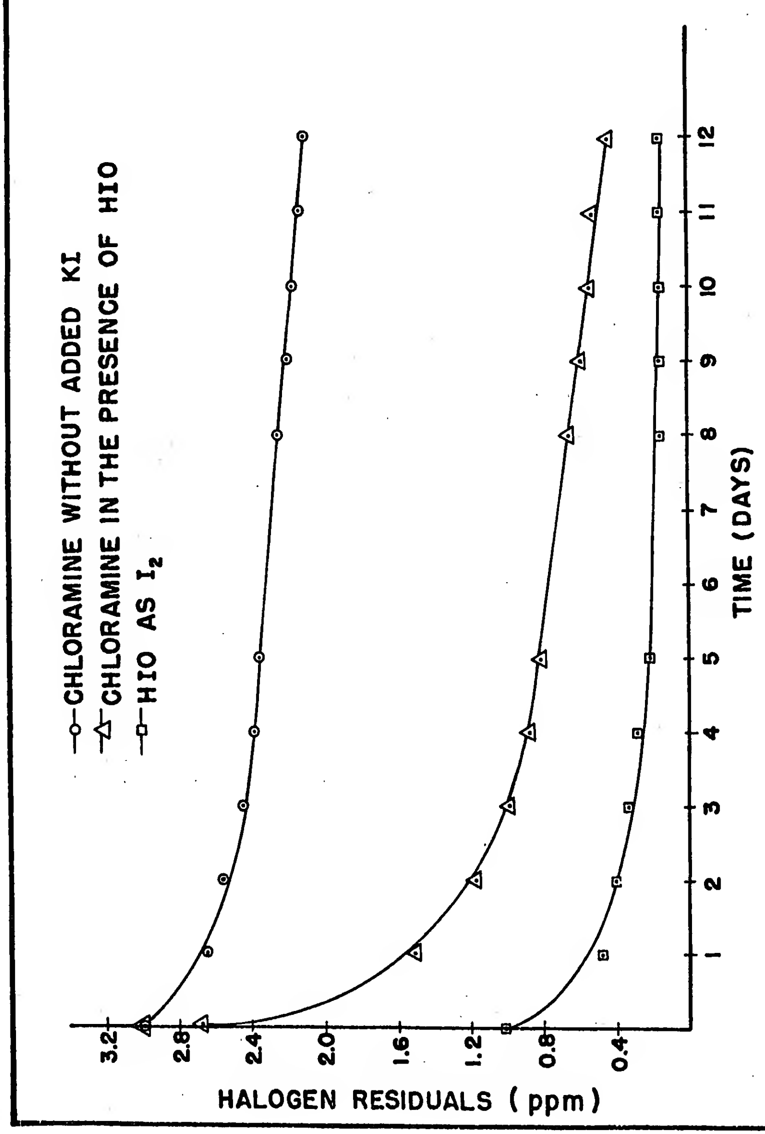

FIG. 29- PERSISTENCE OF HALOGEN RESIDUALS IN GAINESVILLE TAP WATER STORED IN GLASS CONTAINERS

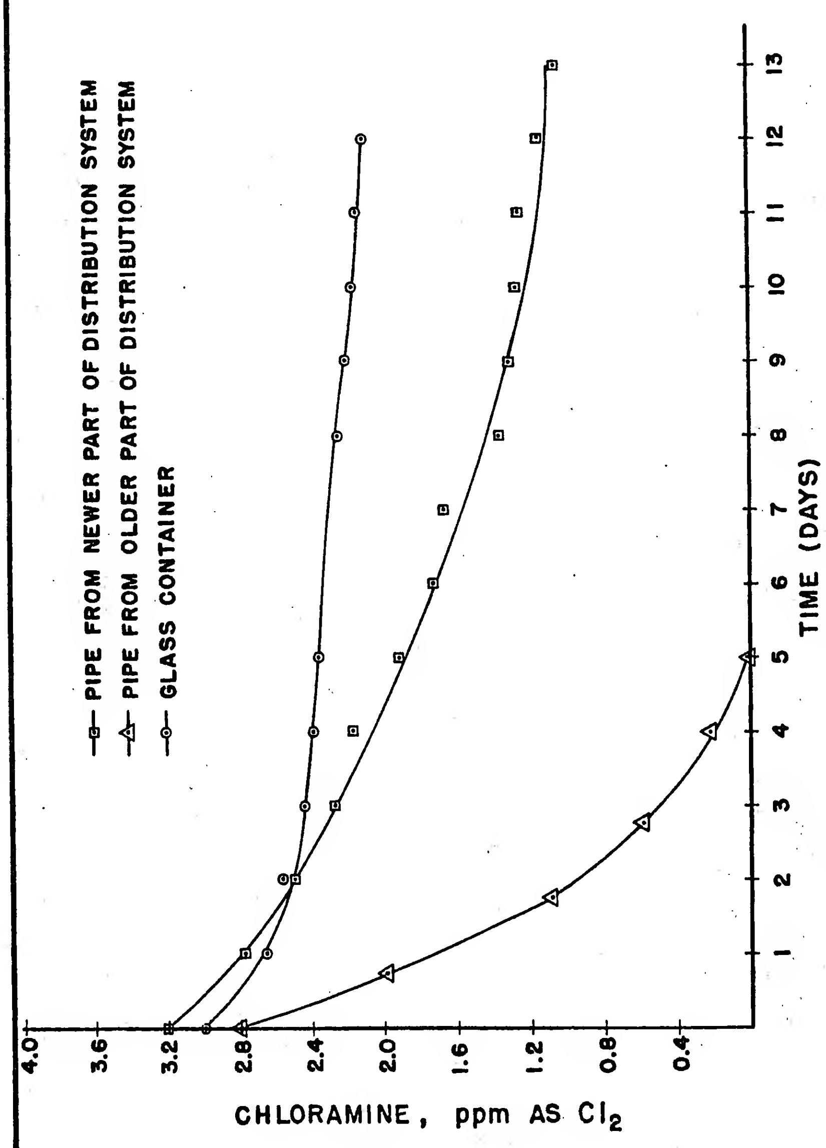

FIG.30 — PERSISTENCE OF CHLORAMINE WITHOUT KI

are shown in Figures 29, 31 and 32. The rapid drop in chloramine concentration in the presence of HIO suggests that oxidation proceeds at a much more rapid rate than when chloramine alone is present. With time, however, much of the demand which was satisfied by chloramine plus HIO could be satisfied by chloramine alone.

These data seem to complement the findings of Berg[11] who showed that HIO acts several times faster than chloramine as a disinfectant.

Importance of reoxidizing the iodide ion. - An estimate of the amount of chloramine consumed in oxidizing the iodide ion to HIO can be obtained from the difference between the concentration of chloramine alone and that of chloramine in the presence of HIO.

Calculations based on data presented in Figures 29, 31 and 32 indicate that a quantity of iodide in the range of 4.0 to 6.6 ppm was oxidized to HIO. This was arrived at by considering the maximum difference in concentration of the chloramines and not necessarily the difference at the end of the test.

The iodine demand of treated water may also be obtained by dechlorinating the water and then determining the iodine demand. Figure 33 shows that an initial iodine concentration of 16 ppm is required in order to maintain a 1 ppm residual at the end of 24 hours.

While there are fallacies in making a direct comparison between the amount of HIO oxidized by chloramine and the iodine demand of dechlorinated water, the data still serve a useful purpose. They show that reuse of the iodide ion through reoxidation by chloramine is a practical means of using a low concentration of iodine as a disinfectant for water.

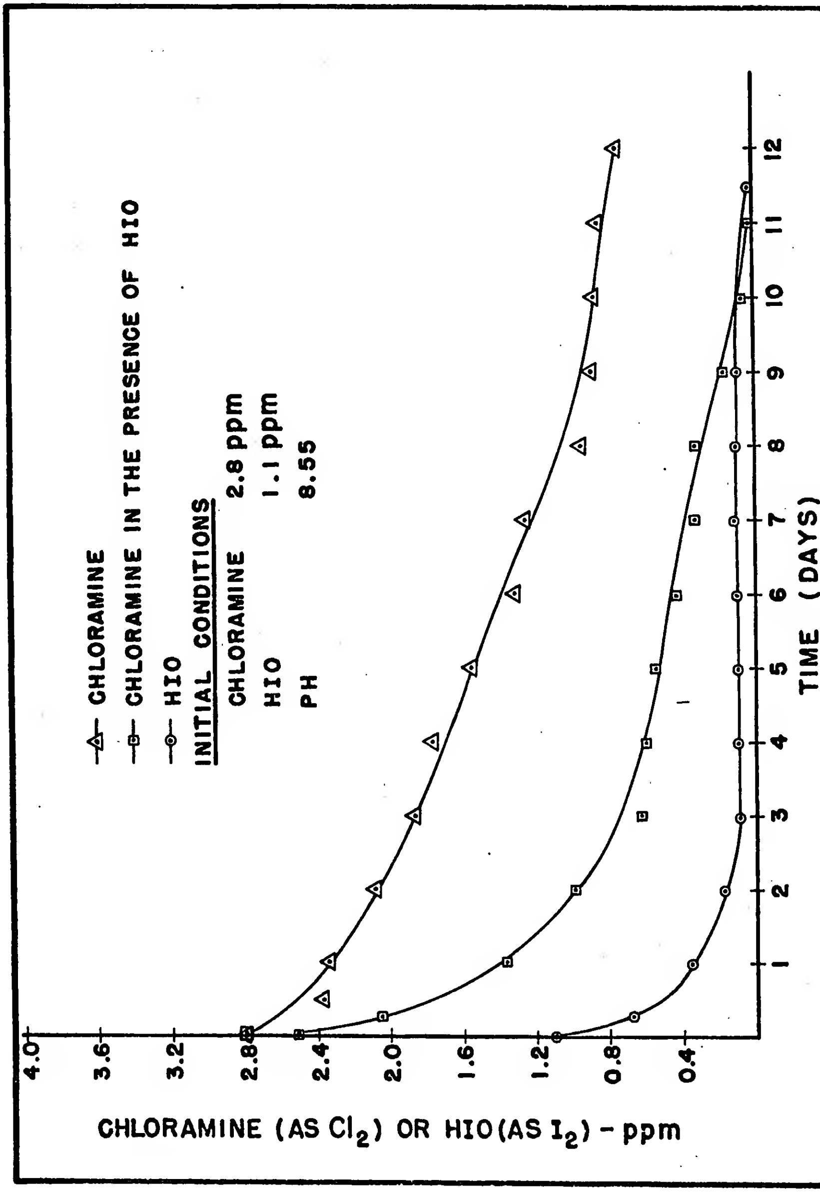

FIG. 31 - PERSISTENCE OF HALOGEN RESIDUALS IN THE NEWER PIPE

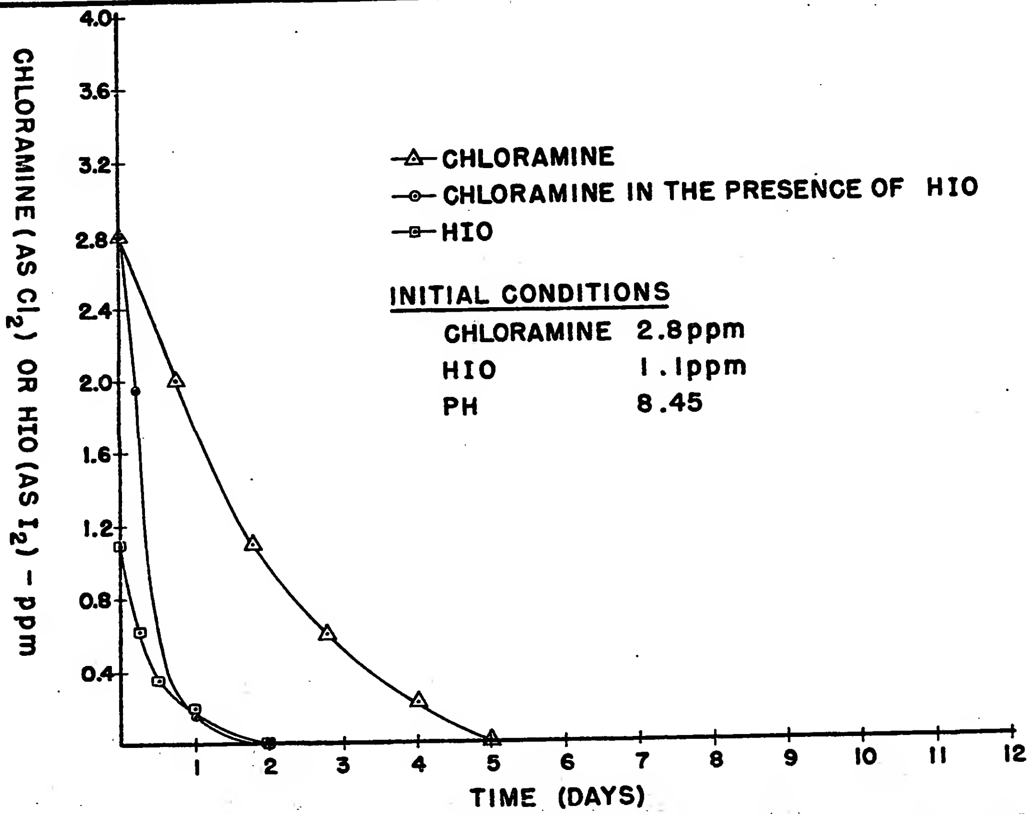

FIG.32 - PERSISTENCE OF HALOGEN RESIDUALS IN THE OLDER PIPE

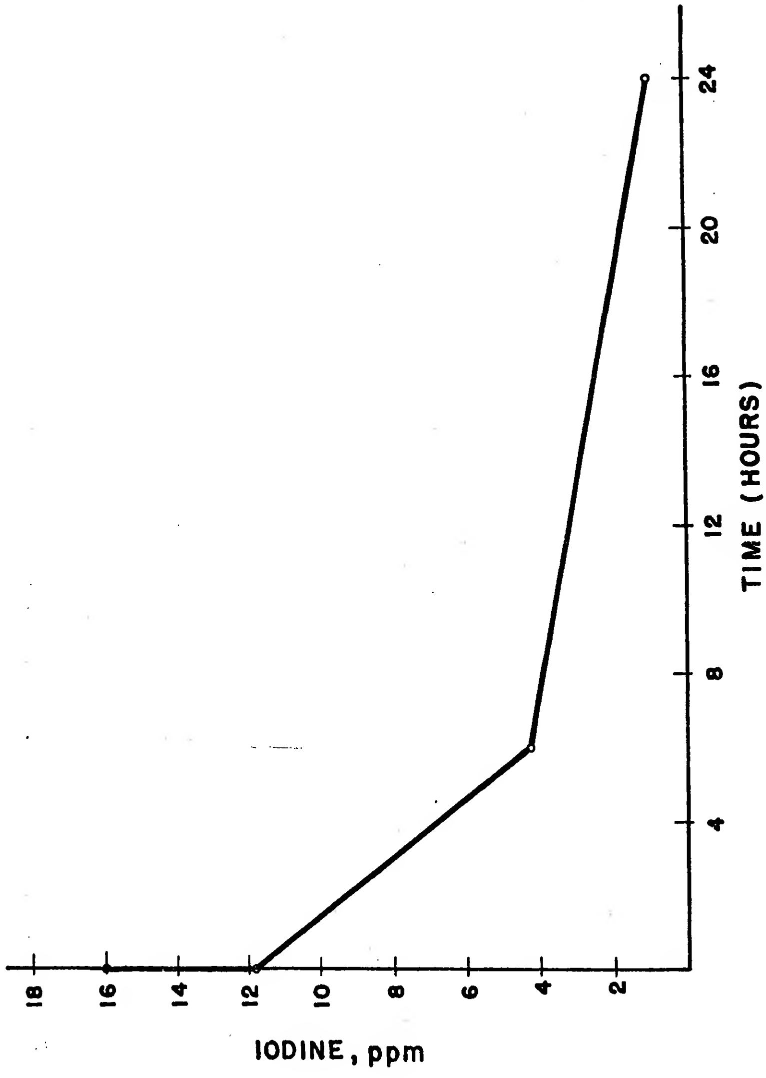

FIG. 33 - IODINE DEMAND OF DECHLORINATED GAINESVILLE TAP WATER

<u>Taste and odor</u>. - During some of the first experiments using both the older and newer pipe sections an odor was detected in the dead air space above the water level. Subsequent experiments included the evaluation of taste and odor.

These evaluations made by laboratory taste panels showed that taste and odor which developed within 24 hours was barely detectable by some and not by other members of the panels. More than 48 hours was required before either became pronounced. It was felt that if the detention time of the distribution system was 48 hours or less a brief system trial was warranted.

<u>Detention Time of the Distribution System</u>

The method which was chosen to approximate the detention time in the distribution system had the advantage of being reliable, easily detected and inexpensive. The method consisted of simply stopping the soda ash feed to the Accelator thereby increasing the noncarbonate hardness of the water. The increase in total hardness from a normal of about 90 ppm at the time of the test to 110 ppm could easily be detected by EDTA titration.

At 8;00 AM, Feb. 20, 1967, the soda ash feeders at the water treatment plant were turned off. By determining the length of time required to observe the increase in hardness at selected points in the distribution system, contours showing detention time could be drawn. During the 48-hour test period water usage averaged 9.1 mgd. From Figure 34 it can be seen that within 24 hours the harder water had covered most of the city. A detention time of 48 hours was exceeded in

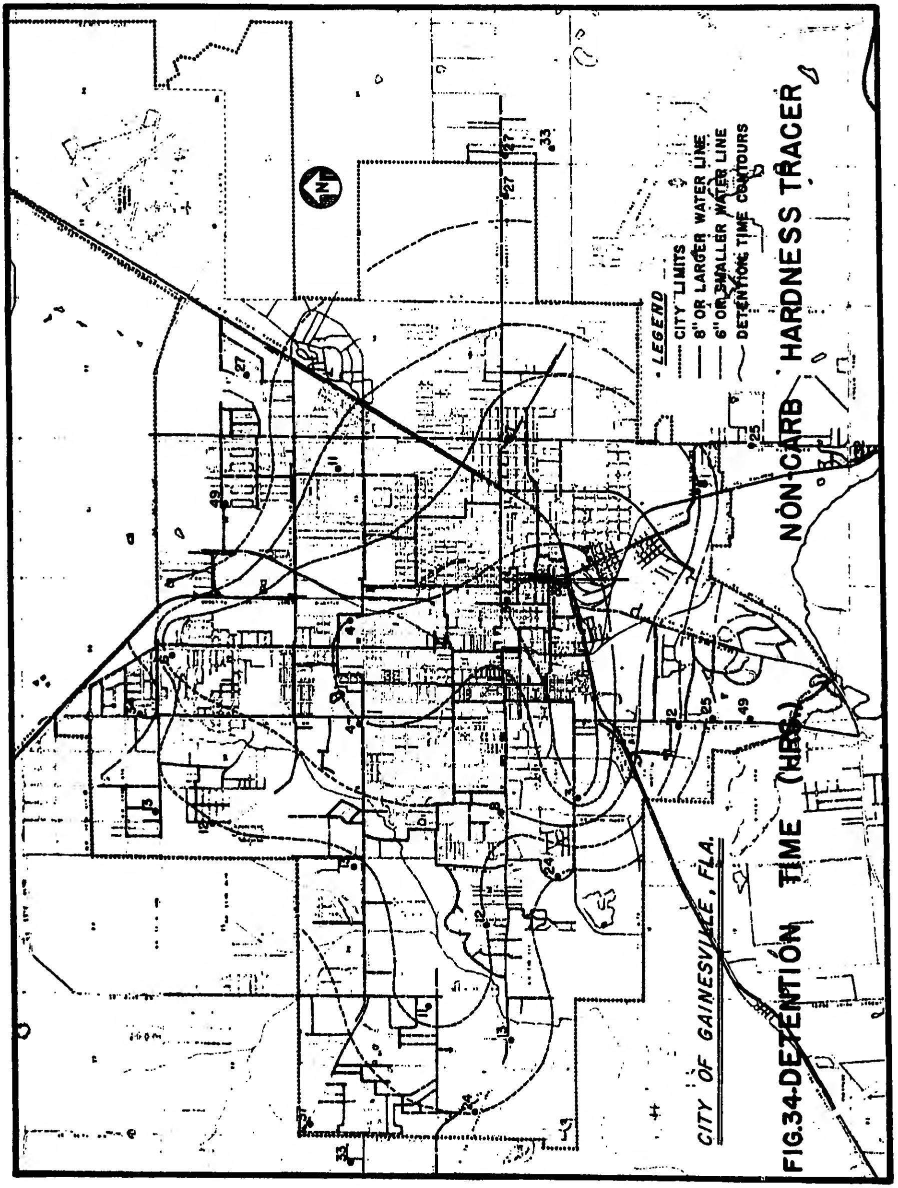

FIG.34. DETENTION TIME (HRS) NON-CARB HARDNESS TRACER

only three areas served by dead-end mains.

Based upon all of these data, it was believed that if taste and odor should develop in the distribution system, it would be present only at the extremities of the city or in areas served by dead-end mains. It was felt that although some element of risk was involved, a system trial was warranted in order to determine the direction to be taken in future efforts, particularly since any change in the bactericidal or viricidal quality of the water would be for the better.

Iodination of the Gainesville Water Supply

Potassium iodide feed. - The concentration of potassium iodide feed solution was determined by considering the pumping range of the Wallace and Tiernan hypochlorinator used as the feed pump and the average amount of water treated daily in the water treatment plant. A solution containing five pounds of potassium iodide per gallon was required.

Point of application. - The potassium iodide solution was added to the water in the flume between the recarbonation basin and the sand filters. This point was chosen primarily because of the lower pH (8.6) of the water and the fact that most of the chlorine exists as chloramine. Both of these factors minimized the possibility of forming iodate due to either the high pH or the presence of free chlorine.

Mixing. - Mixing was provided by a jet of water from a fire hose directed at about a 45^{o} angle into the flume. The potassium iodide solution was applied immediately in front of the jet where the turbulence was greatest. While mixing was accomplished rather rapidly a brown color could be seen momentarily where the KI solution came in contact with the

water.

Trial run. - Eight AM, Feb. 23, 1967, marks the beginning of what is believed to be the first application of iodine to the water supply of a major city for the purpose of water disinfection. The potassium iodide feed was adjusted to provide a residual of 1.0 ppm of HIO, expressed as iodine. Iodine residuals determined at preselected points throughout the distribution system during the next 24 hours are shown in Figure 35. The results show that a disinfecting iodine residual was maintained throughout the system.

Iodination was terminated after 12 hours due to the presence of an objectionable taste and odor. The immediate appearance of an objectionable taste and odor had not been predicted by any of the laboratory tests.

Formation of iodates. - Samples of water were collected at preselected points throughout the distribution system in order to determine if the rate of formation of iodate was significant. All samples were collected between 12 and 24 hours after iodination was begun.

Since both chloramine and HIO were present in the water, the difference between the determined value for total iodine and the sum of the values for iodate ion and HIO, was reported as iodate. The average of 17 samples was 0.08 ppm and the highest value recorded was 0.18 ppm. The values obtained for chloramine, HIO and iodate are tabulated in Table 55. Values for HIO were determined during the test and the others later as shown in the table.

Samples were subsequently set in direct sunlight for approximately

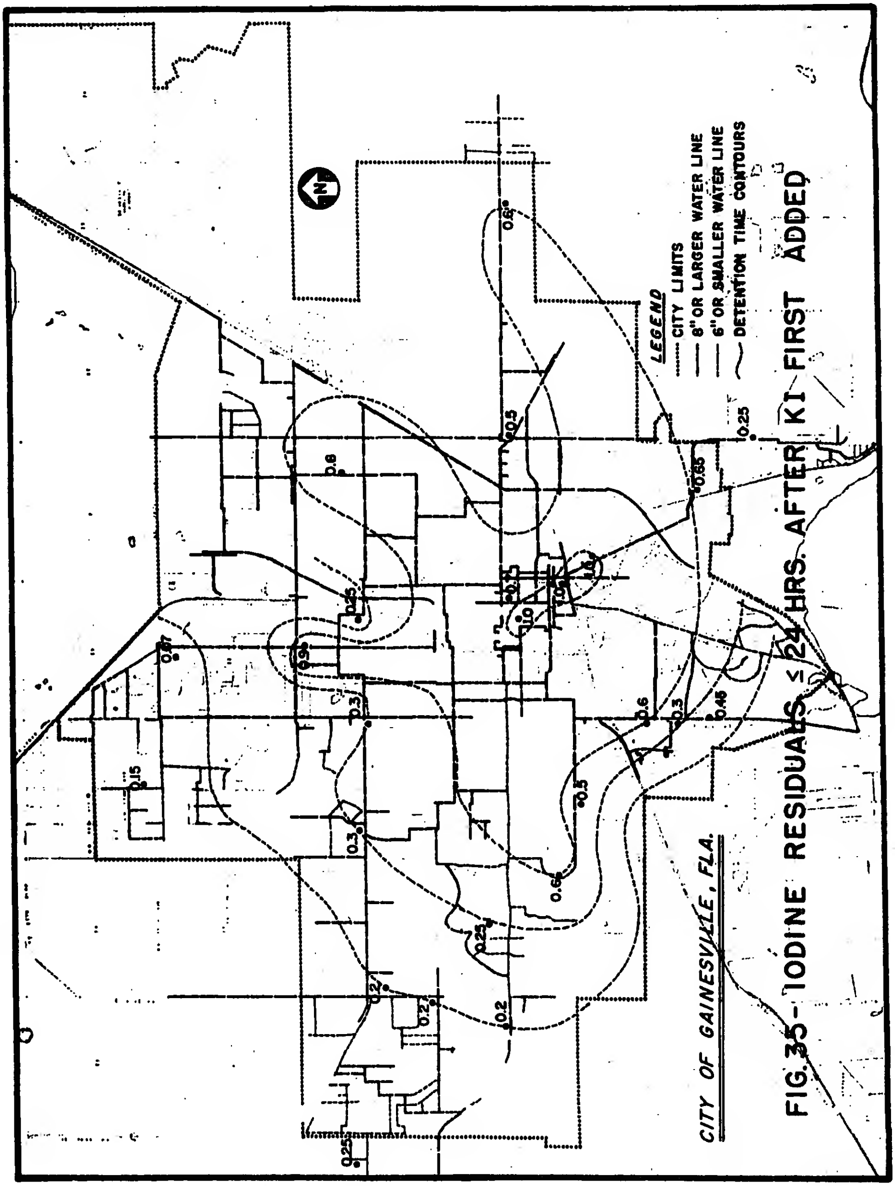

FIG. 35 - IODINE RESIDUALS ≤ 24 HRS. AFTER KI FIRST ADDED

Table 55

Halogen Residuals in Water Collected from the Distribution System During the Period of Iodination

Sample No.	NH_2Cl Mar. 4	HIO Feb. 24	HIO Mar. 4	IO_3^- Titrated March 4	IO_3^- Colorimetric Apr. 7	Iodide Apr. 12	pH Mar. 4
1	1.73	.25	.04	.05	0	.12	8.4
2	1.67	.50	.12	.08	0	.26	8.4
3	1.48	.90	.18	.14	0	.30	8.4
4	1.46	.07	0	.02	0	.06	8.6
5	1.43	.25	0	.03	0	.08	8.6
6	1.42	1.0	.25	.18	0	.30	8.3
7	.67	.25	.15	.11	0	.30	8.6
8	1.39	.15	0	.02	0	.07	8.7
9	1.36	.10	0	.05	0	.10	8.5
10	1.05	1.0	.23	.05	0	.30	8.3
11	1.18	.15	0	.06	0	.16	8.1
12	.95	.25	.07	.05	0	.20	8.45
13	1.18	.80	.25	.17	0	.31	8.50
14	1.45	.60	.08	.10	0	.21	8.7
15	1.37	.45	.17	.12	0	.26	8.6
16	1.60	.30	.08	.08	0	.15	8.5
17	1.30	.25	0	.07	0	.18	8.6

three weeks until the chloramine residual dropped to zero. Iodate was then redetermined on April 7 using the Black and Whittle[83] colorimetric method. The results which are tabulated in Table 55 show no trace of iodate.

The presence of iodides on April 12 in concentrations approximately equal to the total of IO_3^- + HIO on March 4 suggests that IO_3^- may have been reduced to iodide by some unidentified chemical reducing agent or possibly by reducing bacteria.

Additional laboratory studies. - Additional laboratory studies confirmed the earlier evaluation of taste and odor which showed that an objectionable taste and odor should not have been expected to form within 24 hours after the addition of iodine to the city's water supply. Laboratory studies are presently centered around a careful evaluation of several factors which could possibly have contributed to the formation of taste and odor, employing more refined methods for better evaluating their intensity.

VII. SUMMARY AND CONCLUSIONS

The City of Gainesville, Florida, is located over one of the most extensive and productive ground water bearing formations in the continental United States. In the Gainesville area it consists of two very permeable strata of limestone separated by a rather impervious stratum of limestone and dolomite. Solution-type or Karst topography is present throughout much of the area, permitting surface waters or surface pollution to enter the underlying aquifers.

In 1964, sewage pollution became evident in wells No. 4 and No. 6 of the city's well field. These wells were subsequently deepened and the upper stratum cased out. Materials of sewage origin which were entering the ground through Alachua Sink to the south and a sinkhole on the University of Florida campus to the west were believed to be the source of the pollution.

After numerous dye tests traced water from the sinkhole on the University of Florida campus into the city's wells, the sink was sealed off and sewage effluent diverted into Lake Alice which is drained by two shallow wells. Subsequent dye tests at Lake Alice, Alachua Sink and other sinkholes in the area failed to show a connection between any of them and the city's wells, even though sewage pollution continued to be evident in several of the city's wells.

Eight sample points were selected to determine the extent of ground water pollution in the Gainesville area. The results of both

chemical and bacteriological determinations showed that pollutants of sewage origin were present in water in the city's well field and in the area both south and west of that point.

Iodide in water from Lake Alice served as a unique tracer to show that water entering the ground through two drainage wells reappeared in wells owned by the University of Florida and the City of Gainesville. Its apparent appearance in well No. 6 adds strength to the hypothesis that pollutants can migrate from the upper to the lower strata should a route exist. The highly colored water from Alachua Sink is believed to be the source of color which is found in many of the city's wells open to the upper permeable stratum.

A corollary experiment conducted at Lowell, Florida, showed that ^{131}I in the effluent of a sewage treatment plant appeared in a well located approximately 1,000 feet from the sewage treatment plant within three to four days.

A bacteriological study beginning with untreated water, through the water treatment plant and to the consumer, showed that even though the untreated water was of questionable quality, a water which met the 1962 Drinking Water Standards of bacteriological quality was being delivered to the consumer.

The iodination of a private water supply in another state which contained high concentrations of ammonia and other industrial pollutants showed that a low HIO residual could be maintained in the presence of these industrial pollutants.

The water system of the City of Gainesville met the requirements

for a large, yet polluted, water supply and was selected for further study. Laboratory studies using pipe which had been removed from both the older and newer parts of the distribution system showed that a low HIO residual could be maintained for at least 48 hours in the presence of chloramine when an initial concentration of one part per million of iodide was used.

Both taste and odor slowly developed in each pipe; however, 48 hours were required for either to become objectionable.

The detention time in most of the distribution system was determined to be less than 24 hours, with a detention time of 48 hours being exceeded in only a few areas served by dead-end mains.

The water supply was iodinated for a brief period of time by the addition of one part per million of iodine as the iodide ion to the chloramine residual leaving the water treatment plant. Iodination was terminated 12 hours later due to the presence of an objectionable taste and odor in the water which had not been predicted by laboratory tests.

Data which were collected during the trial run demonstrated that an HIO residual was maintained to the ends of the distribution system by reoxidation of the iodide ion. Likewise, iodate determinations made on 17 samples collected from the distribution system during the period of iodination showed that the rate of formation of the iodate ion was very slight.

Subsequent laboratory studies have not reproduced the immediate taste and odor which were observed in the distribution system.

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BIOGRAPHICAL SKETCH

William Paul Bonner was born on July 7, 1931, in Bowdon, Georgia. His childhood was spent in Bowdon where he completed his secondary education in June, 1948. Upon completion of two years of study at West Georgia College he entered the University of Georgia where he received the degree of Bachelor of Science with a major in chemistry in June, 1952. After leaving the University of Georgia he has been employed by Union Carbide Corporation, Nuclear Division, at Oak Ridge, Tennessee, except for a brief tour of duty in the United States Army where he served as an instructor in the Chemical Corps School at Ft. McClellan, Alabama.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Engineering and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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